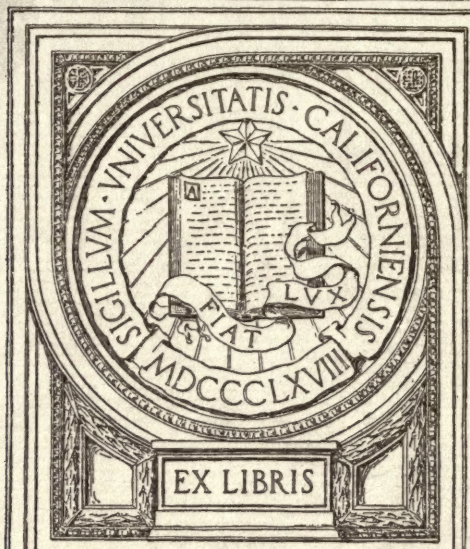
HYDROELECTRIC DEVELOPMENTS AND ENGINEERING

FRANK KOESTER

A. E. & M. E.
LIBRARY
DO NOT TAKE FROM ROOM

GIFT OF
ASSOCIATED ELECTRICAL AND
MECHANICAL ENGINEERS



MECHANICS DEPARTMENT

Engineering
Library

By the same author

STEAM-ELECTRIC POWER PLANTS

A Practical Treatise on the Design of Central Light and Power Stations and their Economical Construction and Operation.

11 x 8 Inch. 473 Pages. 500 Figures

Net, $5.00 (See Last Page)

A.E.&M.E
UNIV. OF CAL

HYDROELECTRIC DEVELOPMENTS AND ENGINEERING

A PRACTICAL AND THEORETICAL TREATISE ON THE DEVELOPMENT, DESIGN, CONSTRUCTION, EQUIPMENT AND OPERATION OF HYDRO-ELECTRIC TRANSMISSION PLANTS

UNIV. OF CALIFORNIA

BY

FRANK KOESTER

CONSULTING ENGINEER, ASSOC. MEM. AM. INST. E. E.
MEMBER SOCIETY GERMAN ENGINEERS (BERLIN), AUTHOR OF "STEAM-ELECTRIC POWER PLANTS"

WITH 500 ILLUSTRATIONS

SECOND EDITION



NEW YORK
D. VAN NOSTRAND COMPANY
23 MURRAY AND 27 WARREN STREETS
LONDON: CONSTABLE & CO., LTD.
1911

TK1081
K7
1911
Engineering
Library

UNIV. OF
CALIFORNIA

MECHANICS DEPT.

COPYRIGHT, 1909
BY
D. VAN NOSTRAND COMPANY

ALSO ENTERED AT
STATIONER'S HALL COURT,
LONDON, ENGLAND

All Rights Reserved

Dedicated

To my Brothers

JOHANNES KOESTER, Consulting Engineer
Klagenfurt, Austria

FRITZ KOESTER, Chief Engineer
Hamm, W., Germany

749202

PREFACE.

Owing to our supposedly inexhaustible coal supply, interest in hydraulic development has naturally been of tardy growth until recent years; and it is only lately that the government has taken steps toward the development and commercial use of water power resources and the preservation of the forests.

In Europe the limited coal supply early induced the utilization of the water resources; and the various Continental governments encouraged this movement by granting favorable franchises, and in many cases advanced money to finance the undertakings, at the same time protecting the water-sheds by rigid enforcement of forest preservation laws. It is but natural, therefore, that hydraulic developments and electric transmission received early and special attention abroad, and as a result Europe abounds in hydraulic developments, utilizing heads varying from 16.5 inches to 3116 feet.

Believing that the progress in hydroelectric engineering is stimulated by the interchange of American and European ideas, and having had considerable practical experience, both here and abroad, the author presents this volume as comprehending the most advanced American and European practice, and trusts that numerous novel features of hydraulic, mechanical, and electrical engineering are made obvious. To point out a few of the new features, the following are cited: Air-shafts and equalizing chambers in connection with pressure tunnels. Seamless-welded, flangeless, telescoping penstocks to facilitate shipment and to eliminate expansion joints. Siphon system, in contradistinction to the inverted siphon — which latter is a misnomer. Impulse wheels with draft tubes and multiple, non-water-wasting nozzles. Compound turbine on a single shaft, the discharge of one being the supply of the other. Rapid and complete turbine tests by curtain methods and autographic recording device. Thirty-thousand-volt generators and their efficient protective devices against lightning. Unique combination of single and three-phase high-tension transmission systems from three-phase generators. Wagon-panel switchboard systems. Segregation and decentralization of switchboards. Continuous water-flow grounders and horngaps with micrometric setting. Two-legged transmission towers and line-crossing protection.

It is not the object of the engineer as a designer of hydroelectric developments to design any particular machine, such as a turbine, generator, transformer, etc., but to provide, by selection from the different makes, an assemblage of machines and devices, each designed to perform its particular function in the most economical manner, and to have the machines properly combined to form one complete unit for the purpose

of generating and transmitting electrical current from water power on a satisfactory commercial basis. Being of the opinion that a good illustration may tell more at a glance than a long discussion, numerous cuts are presented to readily show the present standing of the American and European Hydroelectric Engineering. Reports, maps, and charts on rainfall, evaporation, and run-off may be directly acquired from the various governments, and therefore are not herein given.

As engineers, students, and others desire suggestions and examples in the same or similar lines of work as executed by engineers of standing, there are given in Part III descriptions of several hydroelectric developments, distinctive in their individual features. From these the experiences and opinions of various authorities and examples of their works are given; for instance, the Niagara, Lockport and Ontario Power Company's development is an epitome of papers by five authorities.

The following eight examples are chosen as representative plants of America and Europe: — The Ontario Power Plant (medium head) and its 60,000-volt transmission system; The Great Falls Plant (low head), Charlotte, N. C., with its 11,000 and 44,000-volt lines, together with data on the fundamental requirements regarding the development, source, and market for power. The Necaxa Plant, Mexico, which gives excellent examples of a high head development, and a 170-mile, 60,000-volt (ultimate voltage 80,000) distribution. In the description of the Kykkelsrud-Hafslund system the parallel operation of two prominent Norwegian low head plants is presented. The Urfttalsperre plant (medium head), Germany, the most prominent of the kind in Europe, furnishes striking examples of how to harness the yearly run-off and to husband natural resources in low mountainous countries. The unique price scale adopted enables the consumer to secure power as low as 0.9 to 1 cent per K.W. hour. Another German plant, the Uppenborn, embodies many novel features in its low head development and 50,000-volt transmission lines, and also illustrates the effect of high voltage on a telephone system. The Brusio Plant (1300 feet head) and its 50,000-volt Swiss-Italian transmission system, probably surpasses all other hydroelectric undertakings because of its many new features.

Some discussion has arisen among American engineers as to the practicability of direct generation of high voltages and the consequent elimination of step-up transformers. For many years Continental Europe has had several high voltage generator plants in operation, and that in Manojlovac, Dalmatia, is the latest and foremost of the kind, having four 6000-HP. Francis turbines connected to 30,000-volt generators. The current is transmitted over a 21-mile aërial line, sufficiently protected against lightning by simple devices.

It is hoped that the engineer in general, architect, and student, also the manufacturer, promoter, and financier will find in the text and illustrations a systematic and comprehensive treatise on hydroelectric plants from their inception to the delivery of power to the substation and consumer.

FRANK KOESTER.

New York City,
April, 1909.

ACKNOWLEDGMENTS.

THE author is indebted to American Institute of Electrical Engineers for embodied paper, by D. R. Scholes, "Transmission-Line Towers and Economical Spans;" also to those whose works have been consulted as indicated throughout the volume.

For coöperation: United States Geological Survey; Ambursen Hydraulic Construction Company; National Wood Pipe Company; Excelsior Wooden Pipe Company; Wyckoff Wood Pipe Company; The Pelton Water Wheel Company; J. P. Morris Company; Allis-Chalmers Company; S. Morgan Smith Company; The Dayton Globe Iron Works Company; The James Leffel & Company; Escher Wyss & Co.; J. M. Voith, Maschinenfabrik; The Lombard Governor Company; Replogle Engineering Company; General Electric Company; Westinghouse Electric and Manufacturing Company; Siemens-Schuckert Werke; Allgemeine Elektricitäts-Gesellschaft; Ganz & Co.; Brown, Boveri & Co.; Maschinenfabrik Oerlikon; Elektrizitäts-Gesellschaft Alioth; Archbold-Brady Company; Aermotor Company; The Locke Insulator Manufacturing Company; The R. Thomas & Sons Company.

From the technical press: Engineering News; The Engineering Record; Electrical World; Electrical Review and Western Electrician; Electrical Railway Review; Power and The Engineer; Cassier's Magazine; Electric Journal; The Electrical Age; Transactions of American Society of Civil Engineers; Transactions of American Institute of Electrical Engineers; Transactions of American Society of Mechanical Engineers; Zeitschrift des Vereines deutscher Ingenieure; Schweizerische Bauzeitung; Elektrische Kraftbetriebe und Bahnen; Elektrotechnik und Maschinenbau; Elektrotechnische Zeitschrift; Bulletin technique de la Suisse; Journal le Génie Civil.

For collaboration and courtesies extended: V. C. Converse, engineer in charge, The Ontario Power Company, Niagara Falls; R. D. Mershon, consulting engineer, New York; C. A. Mees, engineer in charge, Southern Power Company, Charlotte, N. C.; Dr. F. S. Pearson, consulting engineer, New York; R. F. Hayward, general manager, The Mexican Light and Power Company, Mexico; C. E. Parsons, chief engineer, Hudson River Electric Power Company, Albany, N. Y.; P. P. Barton, general manager, Niagara Falls Power Company, Niagara Falls, N. Y.; E. W. Coleman, general manager, Great Northern Power Company, Duluth, Minn.; F. G. Sykes, general manager, Portland Railway Light and Power Company, Portland, Ore.; J. W. Young, vice president, McCall Ferry Power Company, McCall Ferry, Pa.

Also the assistance of C. B. Starbird is acknowledged with due appreciation.

TABLE OF CONTENTS.

PART I.

THE TRANSFORMATION OF WATER POWER INTO ELECTRICAL ENERGY.

CHAPTER I.

PROPOSITION.

INVESTIGATION 3

FOREST PRESERVATION 4

HYDRAULICS 5

Laws of Hydraulics — Gross Horsepower — Miner's Inch — Weir Dam — Flow of River — Profile of River — Government Reports.

ECONOMY IN DEVELOPMENT 15

Preliminaries — Problems Involved — Designing Staff — Drawings and Specifications — Field Office.

CHAPTER II.

DAMS.

GRAVITY DAMS 19

Masonry Dams — Reinforced Concrete Dams, Coffer Dams — Crib Dams — Timber Dams — Steel Frame Dams — Earth Dams.

MOVABLE DAMS 32

Stony Gate Dam — Butterfly Dam — Bear Trap — Cylindrical Dam — Needle Dam — Chanoine Dam — Flashboards.

FISHWAYS 37

CHAPTER III.

HEADRACE.

SCHEME 39

CONDUITS 40

Cross Section of Conduits — Trenches — Masonry Flumes — Wooden Flumes — Protection of Flumes — Tunnels — Pressure Tunnels — Friction in Tunnels — Seepage in Tunnels — Construction of Tunnels — Siphon System.

RACKS AND GATES 47

Racks — Screens — Wooden Sluice Gates — Iron Sluice Gates.

COLLECTING BASIN 56

Scheme — Sand Traps — Spillways — Gate Valves.

CHAPTER IV.

Penstocks.

PAGE

Steel Penstocks 59
Penstock Run — Size of Penstocks — Friction — Loss of Head — Strength of Penstock — Construction of Steel Penstocks — Flanges — Anchors — Saddles — Expansion Joints — Safety Devices — Standpipes — Protection of Penstocks

Wooden Penstocks 78
Adaptability — Spacing of Bands — Friction — Durability — Cost — Construction of Wooden Penstocks.

Reinforced Concrete Penstocks 86
Adaptability — Material — Reinforcement — Strength — Construction.

CHAPTER V.

Power Plant.

General Arrangement 88
Forebay — Low Head Plants — Medium Head Plants — High Head Plants.

Excavation and Foundation 102
Selection of Site — Test Holes — Character of Soil — Bearing Power of Soil — Weight of Masonry — Wooden and Concrete Piling — Test of Piles — Concrete Mat Construction — Foundations — Anchor Bolts — Grouting.

Superstructure 107
Architectural Features — Material — Walls — Floors — Roof — Doors — Windows — Stairways and Elevators — Switchboard Gallery — Crane — Heating — Ventilation — Lighting — Lavatories — Conclusions.

Structural Steel 122
Roof Trusses — Columns — Column Bases — Floors — Expansion Joints — Fiber Stresses — Character of Steel — Workmanship — Inspection — Painting — Prevention of Electrolysis.

CHAPTER VI.

Mechanical Equipment.

Turbines 129
Classification — Low Head Turbines — Medium Head Turbines — High Head Turbines — Draft Tubes.

Regulating Devices 143
Principle of Governors — Swiss Governors — Lombard Governor — Replogle Governor — Pelton Nozzle Regulation — Accessories — Couplings.

Oiling System 154
Oil Required — Filtering Tanks — Oil Pumps — Supply Tanks — Oil Piping.

Testing Turbines 157
European Methods — Holyoke Tests.

CHAPTER VII.

Electrical Equipment.

PAGE

Generators 167
Classification — Induction Generator — Revolving Field Generator — Revolving Armature Generator — Regulation — Efficiency — Frequencies — Voltage — Exciters — Generator Leads — High Voltage Generators.

Switching Room 176
General Arrangement.

Switchboards 181
Object — Types — Panel Type — Pedestal or Column Type — Desk or Panel Board — Direct Current Board — Low Tension A. C. Boards — Wagon Panel — High Tension A. C. Boards.

Switchboard Equipment 191
Volt and Ammeters — Wattmeters — Synchronizing — Power Factor Meter — Frequency Meter — Rheostats — Illumination of Switchboards.

Wiring Diagrams 194
System of Wiring Diagrams — American and European Systems.

Bus Bars 201
Size of Bus Bars — Closed Compartments — Open Compartments.

Oil Switches 204
General Remarks — Types of Oil Switches — Circuit Breakers — Overload Relays — Reverse Current Relays — Overload Voltage Relays.

PART II.

THE TRANSMISSION OF HIGH TENSION ELECTRICAL CURRENT.

CHAPTER VIII.

Electrical Transmission.

General Remarks 215

Transmission Conductors 215
Strength of Conductors — Elasticity of Conductors — Cables as Conductors — Spacing of Conductors — Characteristics of Conductors — Size of Conductors — D. C. Conductors — D. C. Problem — A. C. Conductor — A. C. Problem — Transposition — Corona Effect.

Pole and Tower Construction 228

Wooden and Concrete Poles 228
Wooden Poles — Strength of Wooden Poles — Kind of Wood — Cross Arms — Life of Wooden Poles — Preservation of Wooden Poles — Pole Line Construction — Guys — Concreted Wooden Poles — Reinforced Concrete Poles — Steel Pipe Towers.

PAGE

Reinforced Concrete Towers 234

Steel Towers 235

Wind Pressure on Structure — Wind Pressure on Conductors — Sleet — Foundations — Portability — Two Leg Towers — Three Leg Towers — Four Leg Towers — Tretzo Tower — Syracuse Tower — Oneida Tower and Specification — New York Central Tower — Lucerne Tower — Brusio Tower — Suspended Insulator Tower — Line Stresses — Transmission Line Towers and Economical Spans.

Insulators 265

Pin Insulators — Suspension Insulators — Strain Insulators — Insulator Pins — Method of Tying Conductors — Section Switches — Wall Outlets.

CHAPTER IX.

Substations.

General Arrangement 280

Location of Substations — Size of Units — Arrangement of Substations — Ventilation — Drainage — Air-Compressor.

Transformers 286

Type of Transformers — Characteristics of Transformers — Regulation of Transformers — Efficiency of Transformers — Connections — Delta vs. "Y" Connections — Oil-cooled Transformers — Forced Oil-cooled Transformers — Air-cooled Transformers.

Converters 296

Voltage and Frequency — Phases — Field Connections — Starting of Converters — Hunting — Induction Regulator — Compounding — Reactances.

Motor-Generators 302

Frequency Changers 303

Switch Gear of Substations 307

CHAPTER X.

Line Protection.

Lightning Arresters 309

Purpose — Lightning Discharge — Principles of Arresters — Horn Lightning Arresters — Horn-gap Setting — Choke Coils — Multigap Arresters — Action of Multigap Arresters — Insulation of Multigap Arresters — Fluid Arresters — Location of Lightning Arresters.

A.E.&M.E.
UNIV. OF CAL.

PART III. (*Appendix.*)

MODERN AMERICAN AND EUROPEAN HYDROELECTRIC DEVELOPMENTS.

PAGE

Power Plant of the Ontario Power Company, and the Transmission System of the Niagara, Lockport and Ontario Power Company 327

Power Plant of the Southern Power Company, North Carolina, and Its Transmission System 348

Power Plant of the Mexico Light and Power Company, Necaxa, and Its Transmission System 369

Power Plant of the Aktieselskabet Glommens Traesliberi, Christiana, and Its Transmission System 382

The Urfttalsperre Power Plant at Heimbach of the Rurtalsperren-Gesellschaft, Aachen, Germany, and Its Transmission System 393

The Uppenborn Plant at Moosburg of the Städtischen Elektrizitätswerke, Munich, Germany, and its Transmission System 403

Power Plant of the Aktiengesellschaft Kraftwerke Brusio, Switzerland, and the Transmission System of the Società Lombarda Per Distribuzione di Energia Elettrica, Italy 417

Thirty Thousand Generator Voltage Plant, and Transmission System of the Società Per la Utilizzazione Delle Forze Idrauliche Della Dalmazia, Austro-Hungary 435

Index 445

LIST OF ILLUSTRATIONS.

HYDRAULIC MEASURING DEVICE.

PAGE

Weirs 8
Current Meter 11
Plotting Curves for River Discharge 12
Plotting Curves for River Beds 13
Automatic Graphical Registrator 158
Curtain Carriage Tests 159
Flume Tests, Holyoke, Mass. 160

DAMS.

Design of Dams 19, 20, 21
Concrete Dams 22
Cyclopean Masonry Dam 22
Behavior of Resultants in Solid Dams 24
Behavoir of Resultants in Concrete Steel Dams 24
Reinforced Concrete Dams 25
Submerged Power House, Patapco 25
Bar Harbor Plant, Ellsworth, Maine 27
Reinforced Concrete Dam, Ellsworth, Maine 28
Coffer Dams 29
Timber Dams 29
Steel Frame Dams, Hauser Lake 30
Earth Dams, Necaxa, Mexico 31
Earth Dam with Concrete Core, Dixville, N. H. 32
Stoney Roller Sluice Gate Dam 33, 34
Butterfly Dam, Chicago 35
Fishways 37
Dam and Penstock, Necaxa 373
Dam, Heimbach 393, 394

HEADRACE.

Typical Headrace 39
Timber Flume 43, 44
Tunnel and Overflow 46
Lake Poschiava Siphon 47

PAGE

Screen House, Niagara Falls Power Company 48
Racks and Deflector, Hafslund, Norway 49
Screens 50, 51
Vent 50
Penstock Inlet 50
Wooden Sluice Gate 52
Drum Gate 54, 55
Cylindrical Gate 56
Niagara Power Developments 328, 329
Intake of Forebay, Ontario 330
Screen House, Ontario 330
Gate House, Ontario 331
Map of Power Development, Charlotte, N. C. 350
Necaxa Power Development 370
Headrace, Kykkelsrud 387
Gate House and Penstock, Brusio 421

PENSTOCKS.

Flanges 66, 67, 68, 69, 70, 72
Penstock, Anchor 70
Hinged Penstock Support 71
Expansion Slip Joints 71
Expansion Flange Joint 72
Wedge Shaped Expansion Joint 73
Penstock Run, Loch Leven, Scotland 73
Collecting Basin 74
Penstock Arrangement, Brusio 74
Penstock Vent 74
Automatic Flap for Penstocks 75
Vacuum Relief Valve 77
Automatic Low Water Valve 78
Wooden Stave Penstock 79, 80
Detail of Wooden Stave Penstock 82
Penstock Partly Embedded, Ontario 331
Penstock Intake, Necaxa 371

POWER PLANTS.

Chévres, France 54
Lyon, France 56
Georgia, Albany 89
Holyoke, Mass 89
Winnipeg, Manitoba 89
Colliersville, Oswego, N. Y. 90, 91
Shawinigan, Can. 92

A.E.&M.E
UNIV. OF CAL

PAGE

McCall Ferry, Pa. 92, 94
Niagara Falls Power Company 95, 107, 109
Toronto, Can. 96, 97
Kern River, Plant No. 1 ..... 97, 99
Snoqualmie Falls 100
Kykkelsrud, Norway 102
Wooden and Concrete Piles 105
Stuttgart, Germany 110
Obermatt, Lucerne, Switzerland 112
Urfttalsperre, Germany 113
Geneva, Switzerland 114
Sillwerke, Tyrol 120
Tivoli, Rome, Italy 121
Typical Roof Trusses 122
Typical Columns 123
Crane Column 124
Ontario Power Plant and Distributing Station 333–336
Charlotte, N. C. 351, 356
Necaxa, Mexico 374–377
Kykkelsrud, Norway 383–388
Heimbach, Germany 395, 396
Uppenborn, Germany 404, 405
Brusio Power Plant and Penstock Run, Italy 418, 422, 424
Manojlovac Power Plant, Dalmatia 436–438

MECHANICAL EQUIPMENT OF POWER PLANTS.

American Turbine 130
American Turbine, Runner, and Gate 131
Low Head Turbines 132
Vertical Shaft Francis Turbine 133
Double Spiral Francis Turbine 134
Compound Francis Turbine 135
Double Flow Francis Turbine 136
Thrust Bearing 137
Impulse Wheel and Nozzles 138, 139
Francis Spiral Turbine, Horizontal Shaft 140
9700 H.P. Francis Turbine 142
Impulse Wheel Nozzle and Regulator 144
Spoon Wheel Turbine and Governor 145
Turbine Gate 146
Governors 147, 149, 150
Hydraulic Relief Valves 148
Pressure Regulator 150
Pelton Wheel Buckets 151
Automatic Deflecting Nozzle 152

PAGE

Relief Valves 153
Flexible Coupling 153
Oil Filters 154, 155
Oil Filter for Large Capacities 155
6000-Horsepower Francis Turbine 439

ELECTRICAL EQUIPMENT OF POWER PLANTS.

Generator, Two-Phase, Umbrella Type 168
Induction Generator 168
Flywheel Type Generator 169
Three-Phase Generators 171
Exciters 171
Three-Phase Generator 172
Characteristic Curves of Generator 172
Switch and Transformer Room, Obermatt 177
Switch House, Castelnuovo-Valdarno, Italy 178
Shawinigan Falls Plant 179
Puget Sound Plant 180
Switchboard, A. C. and D. C., Necaxa Plant, Mexico 181
Switchboard, Panel and Bench Desk 182
Instrument Columns 183
Switchboard Panel, Rear View, Obermatt 184
Remote Control Switches 185
Instrument Bench Desk 186
Switchboard Panel, D. C. 186
Switchboard, Combined Panel, D. C. 187
Switchboard for Three-Phase Generator 188
Switchboard, Wagon Panel 189
Oil Switch and Bus Bar Compartment 190
Wattmeter Connections 192
Motor Controlled Rheostat 193
Remote Hand Operated Rheostat 194
Wiring Diagram, Valdarno 195
Wiring Diagram, Ontario 196
Wiring Diagram, Necaxa 197
Wiring Diagram for Exciters 198
Wiring Diagram, Urfttalsperre 199
Wiring Diagram, Obermatt 200
Wiring Diagram for Single Generator and Step-up Transformer 201
Circuit Breaker and Bus Bar Compartments 202
Open Bus Bar Compartments, Löntsch, and Luzerne Plants 203
Solenoid Controlled 30,000-volt Oil Switch 205
10,000-volt Air Break Switch 205
11,000-volt Oil Switch, Solenoid Controlled 206
60,000-volt Oil Switch Compartment, Ontario 207
30,000-volt, Motor Controlled Oil Switch 208

PAGE

11,000 and 50,000-volt Oil Switch, Castellanza, Italy 209
88,000-volt Circuit Breakers 210
35,000-volt Switch with Current Blowouts 210
High Tension Time Relay 210
Control Room, Ontario 337
High Tension Bus Bars, Ontario 340
Oil Pipe System for Transformers, Charlotte, N. C. 354
Interior of Generating Room, Charlotte, N. C. 357
Wiring Diagram, Charlotte Plant 358
High Tension Switch Room, Charlotte, N. C. 359
Solenoid Operated Oil Switch 360
Switch Room, Kykkelsrud 389
Generators and Exciters, Heimbach 397
Bus Bar and Switch Room, Heimbach 400
Switchboard, Heimbach 398
Generating Room, Uppenborn 406
Wagon Panel, Siemens-Schuckert, Uppenborn 414
Switchboard, Individual Generator, Brusio 425
Switchboard, Rear View, Brusio 427
Bus Bars, Brusio 427
Exciter Switchboard, Brusio 427
30,000-volt Generator 439

HIGH TENSION TRANSMISSION.

Wooden Poles for 50,000-volt Transmission 228, 229
"A" Frame Tower, 60,000-volt 230
Cross Arm and Guard Wire, 40,000-volt 231
Reinforced Concrete Tower 234
Two-Legged Steel Tower, 37 feet 237
Types of Poles and Towers, 50,000-volt 238
Four-Legged Twin Steel Tower 239
Steel Tower, 45 feet, Syracuse 240
Steel Towers, Niagara Crossing 241
Dead End Steel Towers, Rochester 242
Steel Tower, Standard, New York Central 245
Tower, Bracket and Guard, 35,000-volt, Heimbach 246
Cantilever and Steel Tower, 27,000-volt, Obermatt 246
Steel Tower, 50,000-volt, Piattamala 247
Highway Crossing, 50,000-volt, Lecco 248
Steel Towers, 110,000-volt, Muskegon 249
Steel Tower, Suspended Insulator Type 250
Steel Towers, Diagrams of Different Types 253, 256, 259
Chart for Economical Width of Tower Base 259
Chart for Economical Span 261
Type of Foundation 263
Chart for Sag of Conductors 264

PAGE
Insulator, 40,000-volt, Kern River ... 265
Insulator, 50,000-volt, Taylor's Falls ... 265
Insulator, 40,000 to 50,000-volt, Paderno ... 268
Insulators, Methods of Suspending ... 269
Insulators, Suspended ... 268, 270
Insulator, Suspended 110,000-volt, Muskegon ... 270
Application of Strain Insulators ... 271
Anchor Insulator ... 271
Rolling Insulating for Long Spans, Tofwehult ... 271
Insulator Pin, Porcelain Base ... 272
Insulator Pin, all Steel ... 272
Insulator Pin, Detail, 60,000-volt ... 273
Insulator Tie and Clamp, 60,000-volt, Ontario ... 273
Insulators, 60,000-volt, Ontario ... 273
Line Disconnecting Switch ... 275
Two Break Section Switch ... 276
Typical Wall Outlets ... 276–277
Cross Arm Guard Wire, Lightning Rod ... 323
Transmission Line, 62,000-volt, Ontario ... 341
Niagara Crossing ... 342
Cantilever, Niagara Crossing ... 343
Cross Connection and Open Air Fuse, Auburn ... 343
Four Leg Tower on "Floating" Foundation, Montezuma Swamp ... 344
Transmission System, Charlotte, N. C. ... 349
Transmission Feeders ... 361
Main Transmission Line, Charlotte, N. C. ... 363
Insulator, 50,000-volt, Charlotte, N. C. ... 364
Transmission Line in Cities, Charlotte, N. C. ... 365
Map of Transmission Line, Necaxa ... 378
Transmission Tower, Necaxa ... 379
Transmission Line, Necaxa ... 380
Transmission Line, 50,000-volt, Kykkelsrud to Hafslund ... 392
Wall Outlet, Uppenborn ... 408
Insulators, 50,000-volt, Uppenborn ... 410
Cable Tunnel, Brusio, Piattamala ... 427
Line Crossing, 50,000-volt, Piattamala ... 431
Insulator, 30,000-volt, Manojlovac ... 441
Transmission Line Crossing, Manojlovac ... 442

SUBSTATIONS AND EQUIPMENT.

Duluth Substation ... 110
Stansstad Substation ... 115
Substation, Waterbury ... 281–282
Substation, Typical Three-Phase ... 283–284
Substation, Steghof, Switch Gear ... 285
Transformer, Shell Type ... 286

PAGE

Transformer, Core Type 286
Transformer, Water Circulated, Oil Cooled 287
Chart Showing Efficiency of Air Blast Transformer 288, 289
Transformer Connections to Rotary Converters 291
Transformer, Forced Air Circulation 292
Transformer, Air Cooled 293
Transformer, Method of Water Cooling, Molinar, Spain 293
Transformers, Arrangement of Air Blast 294
Transformer, Chart Showing Air Required 295
Rotary Converter, Substation, Albina 297
Automatic Regulators, Transformer 300
Typical Continental Motor Generator, Substation 302
Motor Generator, Substation, Steghof 303
Frequency Changers 304
Typical Switchboard Panels for Substations 305
Wiring Diagram, Waterbury Substation 306
Distributing Station and Power House, Ontario 333
Control Room, Ontario 337
Distributing Station, Ontario 337
Transformer Compartment 338
High Tension Bus Bars, Ontario 340
60,000-volt Open Air Bus Bars, Lockport 346
60,000-volt Circuit Breaker, Lockport 347
Transformer Room, Charlotte, N. C. 354
Substation, El Oro 381
Transformer Room, Kykkelsrud 390
Substation Interior, Hafslund 391
Transformer Room, Heimbach 399
Transformer House, Typical 402
Transformer and Lightning Arrester House, Hirschau, Uppenborn 411
Transformer Water Flow Grounder, Hirschau, Uppenborn 413
Horn Gaps, Substation, Hirschau, Uppenborn 415
Transformer Station, Piattamala 428
Switch Room, Piattamala 429
Air Cooled Transformer, Open Type, Lomazzo 433
Switch Room, Lomazzo 433

LIGHTNING ARRESTERS.

Horn Gaps, Showing Principle of Action 310
Horn Gaps, Application with Oil Rheostat 312
Horn Gaps, Construction 313
Horn Gaps, Setting 313
Lightning Arrester Equipment, Hirschau, Uppenborn 413
Protection of Overhead and Underground Lines 313
Water-Flow Grounder 413
Station Protection, Torchio 314

PAGE

Protection, 3000-volt Circuit, Gola 314
Multigap Arresters 315, 316
Aluminum Arrester 318, 319
Electrolytic Arresters 320–321
Horn Gaps, Water-Flow Grounder, Steghof 321
Water-Flow Grounders 321–322
Bank of Horn Gaps, Choke Coils, and Water-Flow Grounders, Vandoise 322
Water-Flow Grounders, 50,000-volt, Piattamala 322
Lightning Rod and Guard Wire 323
Lightning Protecting Device, Heimbach 401

LIST OF TABLES.

	PAGE
Discharge of Weirs	9
Velocity of Water in Channels	42
Properties of Timber	53
Tests of American Woods	53
Area of Circles	60
Frictional Head Loss in Penstocks	62
Capacity Discharge of Pipes	63
Riveted Pipes	65
Safe Strain of Penstock Bends	79
Strength of Douglass Fir	81
Cost of Riveted Penstock	82
Comparative Cost of Penstocks	83
Bearing Power of Soil	103
Weight of Masonry	104
Radiating Surface for Heating	117
Comparative Tests of Turbine	161
Modulus of Elasticity of Conductors	216
Coefficient of Expansion	216
Strand Factor of Conductors	216
Comparison of Wire Gauges	218
Solid Copper Wire	219
Stranded Copper Wire	220
Reactance of Volts	221
Weight and Strength of Wires	221
American and English Copper Cable	222
American and English Copper Wire	223
Corrected Wind Velocities	235
Comparative Tests of Transmission Towers	238
Tensile Strength in Conductivity of Conductors	250
Sag of Wires at Different Temperatures	252
Resultant Force in Transmission Towers	262
Air Required for Transformers	294
Air Required for Transformers of 25 and 60 Cycles	295
Spacing Between Multigap Arresters	312
Efficiency of Turbines	352
Efficiency of Generators	355
Efficiency of Exciters	355
Efficiency of Transformers	359
Cost of Hydroelectric Installation	416

PART I.

THE TRANSFORMATION OF WATER POWER INTO ELECTRICAL ENERGY.

HYDROELECTRIC DEVELOPMENTS AND ENGINEERING.

CHAPTER I.

PROPOSITION.

Investigation. Before developing a water power much preliminary study is necessary to ascertain whether the proposition will be a paying one. Reliable data must be collected and put in complete and definite form before capitalists can be interested.

After the investigations are made showing the amount of energy available, the possible field of consumption must be carefully considered. This may include other central stations, either steam, gas, or even other water-power plants. While the selling price of current is known, it might appear difficult to ascertain what it costs existing companies to produce electrical energy. There are, however, several ways by which this information can be obtained, and with the help of an experienced engineer very close figures can be ascertained.

These costs are essential as a guide for the new development, because it may have to compete with or possibly sell current to established stations, and in any event this is the salient factor in determining whether the proposed plant is an advisable development.

In the case of selling power to established electrical systems the plants are customarily operated in parallel. In some instances the separate companies have found it expedient to merge their interests and form a corporation. Having arrived at the competitor's figures, the other prospective fields for current consumption must be thoroughly canvassed, to ascertain the load and the price for which the current can be sold. In fixing the selling price different rates are charged according to the amount, duration, and time of load. Conclusions as to the cost of current can only be derived after trial load-curves have been plotted, and the careful balancing of the engineering and commercial items for each particular plant.

Plants are economical in first cost and in operation in proportion to the constancy of their load factors. With greatly varying loads much machinery is idle a large part of the time. However, in competing successfully with existing central station or private plants, prospective consumers who will require current for only a few hours each day or possibly each week, and those who will need emergency current, must not be overlooked. That these consumers pay a high rate for the service rendered is but natural.

After the foregoing investigations have been made, and the figures show that the installation is warranted, the possible future growth of the locality, such as the industrial increase, electric railroading, etc., must be well considered; with the growth of the community an increase in consumers naturally follows.

Hydroelectric plants have often been installed without provision for future extension; the dams are located in such sections of the rivers, and are of such a design, that an increase in storage supply or additional head is impossible. Plants have also frequently been installed where sufficient water to carry the full load cannot be obtained during certain seasons of the year. While the former may be due to lack of foresight, the latter is attributable to negligence in proper investigation. Under such conditions competition would be difficult. In many cases water-power plants do not have to meet competition, as they may be pioneers in the field. Under favorable conditions the hydraulic plant may be reinforced with a steam or a gas engine plant, this auxiliary equipment taking the load during periods of low water and hours of heaviest demand.

The equipment and size of the units should be such that they will run at their best efficiency throughout the day, that is, they must not run underloaded or greatly overloaded. Reserve units must be kept in readiness to be thrown on the line when the demand calls for them.

Present practice is to install as large units as possible.

FOREST PRESERVATION.

The relation of forests to water-power development is of the greatest importance. It is a well-known fact that the soil of forests retains the water of precipitation more uniformly and releases it gradually, so that during dry seasons a supply of water is assured. Flat non-forested land may hold the water and form swamps, but in most cases the water drains off rapidly, so that streams having denuded watersheds are subject either to floods or droughts.

Long observation and costly experiments have proven that forests receive a greater quantity of rain, hail, and snow than land in the same vicinity. Mountainous countries, whether bare or covered with forest, receive more rain than flat country; and the forests in mountainous countries receive more rain than bare land at the same elevation.

The following data throw some light on the effect forests have on water-power developments.

According to the report by the Swiss engineer, Lauterberg, the drainage of the canton Tessin, between 1834 and 1862, was reduced about 28 per cent, due to the removal of forests. He states further that prior to the destruction of forests the valleys were flooded, on the average, every 54 months, while after the forests were destroyed floods occurred every 29 months. Professor Ebermeyer states that, considering the evaporating factor of free land as 100 per cent, the evaporation of the forest land is only 22 per cent, other conditions remaining the same. Dr. van Bebber observed that a forest at an elevation of 1000 meters (3280 feet) has about

50 per cent more drainage than free land situated on the same elevation. Relative to this, Professor Schreiber, who observed conditions in Saxony, came to the conclusion that forests on open country receive as much precipitation as free land elevated 200 meters (656 feet) higher. Further, Professor Landolt, Zürich, states that for every 100 meters (328 feet) elevation the annual drainage will increase 10 inches.

Between the years of 1843–1883 the Ekaterinoslaw government, Russia, cultivated a forest of 5000 acres, and established two meteorological stations in this section. The reports show that since the introduction of the forest, showers are much more frequent, and the previously feared dry seasons are things of the past. The stations report that the average rainfall between 1893–1897 was 18 inches for free land, while for the forests 22.25 inches.

The French government spent 14,500,000 francs between the years 1861 and 1877 to forestize 235,000 acres in mountainous localities. The result was so beneficial that the government decided to forestize about two million acres additional, which will probably cover 60 to 80 years and consume 150,000,000 francs. Austria has at present very elaborate plans to reëstablish forests in denuded sections. The Italian government has set aside $8,000,000 as a beginning towards the reëstablishment of the forests in the southern Alps. For many years Germany has enforced rigid laws for the preservation of her forests, and in recent years has encouraged and assisted water-power developments.

In May, 1908, the governors of several States discussed the preservation of our national resources, particularly those of forests and water supply. This was due chiefly to the increase in the fluctuation of streams, which is a direct result of the destruction of forests.

Fluctuations of water supply and danger due to floods have forced water-power developments to additional expenditure to harness water of uncertain quantities. For instance,[1] one of the largest power companies had to build new dams 25 per cent greater in cross section than the older ones on the same stream; other hydraulic plants that previously had abundant water are now forced to supplement with auxiliary steam plants.

HYDRAULICS.

Laws of Hydraulics. In 1830, Galileo stated that the laws governing the flow of water were not as well known as those governing the movements of the celestial bodies, and even to-day this is still true. Our experimental data of to-day are far in advance of hydraulic theory, hydraulic engineering being based more on empirical facts than on rational mathematical formulas.[2]

For power purposes water is usually measured in cubic feet of flow per second. The unit weight of water at ordinary temperature is 62.5 pounds per cubic foot. The present theory of the flow of water is based on a few formulas. The fundamental laws of falling bodies apply also to the flow of water. Of course the formu-

[1] Forestry Hearing, Am. Inst. E. E., May, 1908.

[2] Merriman, Treatise on Hydraulics.

las derived from the laws of gravity cannot be directly applied to hydraulics; they must be changed to suit conditions. However, by the judicious use of the fundamental principles and common sense all power problems may be easily solved.

The principal formulas in hydraulic calculations are:

$$v = \sqrt{2gh} = 8.03\sqrt{h}.$$

$$q = av = a\sqrt{2gh} = 8.03 \times a\sqrt{h}.$$

v = velocity of flow in feet per second.
q = quantity of flow in cubic feet per second.
h = head or height through which the water falls.
a = area of cross section of falling body of water.

Whenever the formula for q is applied to water issuing from an orifice, a coefficient must be introduced.

Thus, for water issuing from a circular orifice the quantity coming out is not $q = \frac{1}{4}\ \pi\ d^2\ \sqrt{2gh}$, but $q = c/4\ \pi\ d^2\ \sqrt{2gh}$, where c is the coefficient, whose value depends on the sharpness of the edges of the opening. This is true for the flow of water issuing from a square, rectangular, or, in fact, any shaped orifice. The values of the coefficients in any case never equal unity.

A special case of a rectangular orifice is what is known as the 'weir.' The weir in general is an opening or rather a notch through which the water flows.

The fundamental formula used with weirs is

$$Q = \tfrac{2}{3}\sqrt{2g}\ bH^{\frac{3}{2}}.$$

Q = quantity of water in cubic feet per second.
b = width of opening or notch.
H = height of the water surface above the lowest part of notch.
H is measured some distance back of the weir.

The above formula undergoes many modifications when used in practice. Many coefficients must be used in connection with it. Thus, the shape of the notch, whether rectangular, square, or triangular, the sharpness of the edges, the velocity of approach, the form of curve the water takes in flowing over the weir,— each factor introduces a different coefficient.

When water is carried to the power house by means of open trenches or canals, or through long pipe lines, some energy is lost by friction and change in direction of flow. The formula for loss of energy, usually termed "loss of head," is $h = \frac{v^2}{2g}$. This formula shows that the loss of head varies with the square of the velocity. A very important factor which enters into hydraulic computation is what is known as the hydraulic radius. It is not a radius in the strict sense; it is a ratio and is expressed as follows: — Area of cross section of stream, canal, or pipe, in square feet, divided by the length of the wetted perimeter in lineal feet. This factor is of

great importance when calculating the flow of water through canals, ditches, and pipes.

The slope of a stream, canal, or pipe line is its fall in feet per mile, or is the drop in any measured length.

For the velocity of flow in rivers having a uniform cross-sectional area, with a given slope,[1]

velocity in feet per second $= \sqrt{\text{hydraulic radius} \times \text{slope in feet per mile}}$.

For canals and ditches of uniform area and smooth bottom,

velocity in feet per second $= \sqrt{\text{hydraulic radius} \times 2 \times \text{slope in feet per mile}}$.

By inversion is obtained the formula for the hydraulic gradient or slope for a given velocity in feet per mile.

$$\text{thus} = \frac{(\text{velocity in feet per second})^2}{\text{Hydraulic Radius} \times 2}.$$

A change in cross section will alter the value of the hydraulic gradient, that is, making the ditch or canal wider or narrower, or changing the form. Too swift a velocity must not be chosen, because the water will scour the sides of the canal. Of course when the canal is made of concrete this factor is of little account; the friction loss is of greater importance than the scouring effect of water on concrete.

Gross Horsepower. The gross horsepower of a mass of falling water is

$$\frac{Q \times H \times 62.3}{33{,}000} \text{ or } 0.00189\, QH.$$

Q = cubic feet of water discharge per minute.

H = head in feet.

62.3, weight per cubic foot of water (at 60° F.).

As water is usually measured in cubic feet per second, the above formula is preferably taken as

$$\frac{Q \times H \times 62.3}{550} \text{ or } 0.1134\, QH.$$

To compute the gross horsepower of a running stream the same formula may be used.

H in this case represents the theoretical head due to the velocity of the water in the stream,

$$H = \frac{v^2}{2g} = \frac{v^2}{64.4}.$$

v = velocity of water in feet per second.

Q = cubic feet of water per second.

The gross horsepower $= 0.1134\, QH$.

Water wheels or turbines do not utilize the gross head, as friction in the headrace and in the turbine itself has to be considered.

[1] Hiscox, Hydraulic Engineering, page 57.

Miner's Inch. During the early days of hydraulic engineering in America the Miner's Inch originated in California, and is a method of measurement adopted by the various ditch companies in disposing of water for irrigation and mining. The miner's inch is equal to the flow of water through an orifice one inch square, in a 1.25 inch plank, and the surface of the water being 6 inches above the top edge of the opening. This method of measuring is becoming obsolete and is being replaced by the more accurate system of weir measurements.

Weir Dam. Select a stretch on the stream or ditch which will afford as straight and uniform a course as possible. If the water is carried in a flume through any part of its course, make all measurements in the flume. Lay off a distance of say 300 feet; measure the width of the stream at the surface of the water at about six different places in this distance, and obtain the average width; likewise at these same points measure the depth of water at three or four places across the stream, and obtain the average depth. Next drop a float in the water, noting the number of seconds it takes to travel the given distance. From this can be calculated the velocity of the water in feet per second. The cubic quantity is the product obtained by multiplying the average width in feet by the average depth in feet by the velocity, which (if in feet per second) will give the flow of the stream in cubic feet per second. From the figures so obtained 20 per cent must be deducted, as the surface velocity of the water is greater than the average velocity.

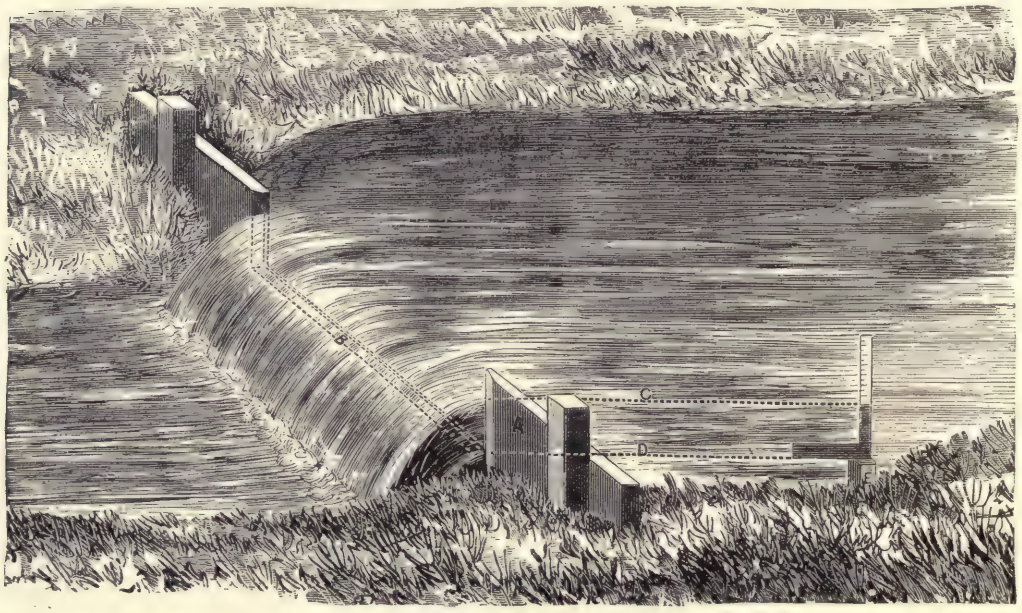


FIG. 1.—Weir Dam.

When the stream is of sufficient depth — say three feet or over — the average velocity can be more easily obtained by using a pole to one end of which is attached a stone or piece of lead of necessary weight to allow the pole to sink nearly to the

A.E.&M.E.
UNIV. OF CAL.

bottom. In this way the velocities at the surface and bottom of the stream counteract one another and a closer approximation to the average velocity is obtained.

Place a board, *a*, across the stream at some point which will allow a pond to form above (see Fig. 1). The board should have a notch, *b*, with both edges sharply beveled towards the intake as shown. The bottom of the notch, called the "crest" of the weir, should be perfectly level and the sides vertical. In the pond back of the weir, at a distance, *d*, not less than the length of the weir, drive a stake, *e*, near the bank, with its top precisely level with the crest. Measure the depth, *c*, of water over the top of stake, and then from Table I calculate the amount of water flowing over the weir.

TABLE I. — SHOWING QUANTITY OF WATER PASSING OVER WEIRS IN CUBIC FEET PER MINUTE.

Depth of water on weir, inches	Cubic feet per minute passed for each foot of length of weir.	Depth of water on weir, inches.	Cubic feet per minute passed for each foot of length of weir.	Depth of water on weir, inches	Cubic feet per minute passed for each foot of length of weir.	Depth of water on weir, inches	Cubic feet per minute passed for each foot of length of weir	Depth of water on weir, inches	Cubic feet per minute passed for each foot of length of weir.
1	4.85	4	38.80	7	89.82	10	153.35	14	254.03
1 1/8	5.78	4 1/8	40.63	7 1/8	92.16	10 1/8	156.20	14 1/4	260.83
1 1/4	6.68	4 1/4	42.49	7 1/4	94.67	10 1/4	159.14	14 1/2	267.77
1 3/8	7.80	4 3/8	44.39	7 3/8	97.11	10 3/8	162.07	14 3/4	274.70
1 1/2	8.90	4 1/2	46.29	7 1/2	99.50	10 1/2	164.99	15	281.72
1 5/8	10.00	4 5/8	48.22	7 5/8	102.10	10 5/8	167.89	15 1/4	288.82
1 3/4	11.23	4 3/4	50.20	7 3/4	104.63	10 3/4	169.92	15 1/2	295.93
1 7/8	12.45	4 7/8	52.18	7 7/8	107.13	10 7/8	173.90	15 3/4	303.10
2	13.72	5	54.22	8	109.74	11	176.92	16	310.36
2 1/8	15.02	5 1/8	56.25	8 1/8	112.31	11 1/8	179.94	16 1/4	317.69
2 1/4	16.36	5 1/4	58.33	8 1/4	114.91	11 1/4	182.99	16 1/2	325.03
2 3/8	17.75	5 3/8	60.42	8 3/8	117.51	11 3/8	186.03	16 3/4	332.42
2 1/2	19.17	5 1/2	62.55	8 1/2	120.18	11 1/2	189.13	17	339.91
2 5/8	20.63	5 5/8	64.68	8 5/8	122.82	11 5/8	192.20	17 1/4	347.45
2 3/4	22.11	5 3/4	66.86	8 3/4	125.52	11 3/4	195.32	17 1/2	355.02
2 7/8	23.63	5 7/8	68.98	8 7/8	128.14	11 7/8	198.47	17 3/4	362.77
3	25.20	6	71.27	9	130.93	12	201.59	18	370.34
3 1/8	26.78	6 1/8	73.45	9 1/8	133.65	12 1/4	207.94	18 1/4	378.12
3 1/4	28.43	6 1/4	75.77	9 1/4	136.43	12 1/2	214.32	18 1/2	385.87
3 3/8	30.06	6 3/8	78.04	9 3/8	139.18	12 3/4	220.76	18 3/4	393.66
3 1/2	31.75	6 1/2	80.36	9 1/2	141.99	13	227.30	19	401.63
3 5/8	33.45	6 5/8	82.63	9 5/8	144.80	13 1/4	233 92	19 1/4	409.58
3 3/4	35.22	6 3/4	85.04	9 3/4	147.64	13 1/2	240.54	19 1/2	417.48
3 7/8	36.98	6 7/8	87.43	9 7/8	150.47	13 3/4	247.22	19 3/4	425.68

There are certain proportions which must be observed in the dimensions of this notch. Its length should be between four and eight times the depth of water over the crest of the weir, and not over two-thirds the width of water on the upstream side; also the pond above the weir should be sufficiently large to reduce the velocity of flow or "approach" to less than 2 feet per second. In order to obtain these results it will probably be necessary to experiment to some extent. An example may serve to better explain this procedure.

First, roughly gauge the stream to be measured, by the cross-section and velocity method. Suppose the width is found to be 4.5 feet, the depth 1.5 feet, and the

average velocity 3 feet per second. The stream is then carrying approximately 1215 cubic feet per minute.

Next it is necessary to ascertain the size of weir to discharge approximately this amount of water. The length of notch must be from four to eight times the depth. Assuming an average of say six times the depth, which will be within the limits, from Table I it will be found by trial that a weir 72 inches long, with a depth of 12 inches, will discharge 1196 cubic feet of water per minute. This, therefore, is approximately the size of weir required.

Take a board of sufficient length to reach well across the stream and cut the notch 72 inches long and about 16 inches deep, as it should be somewhat deeper than the water flowing over it. The vertical height from the crest to water line on downstream side should be at least twice the depth of water on the crest, or approximately 26 inches in this case. If the length of the notch is greater than two-thirds the width of the water above the dam, it is necessary to either construct a higher weir, in order to raise the water level, or to cut away the sides of the bank, as the ratio must not be exceeded.

It is of course essential that there be no leaks around or under the weir. All the water must pass through the notch. Canvas or sacking laid under the water against the dam will be found effective in this connection. With the weir so constructed, measure the depth of the water over the stake, and by the use of the table ascertain the actual quantity flowing over the weir.

Table I will give results sufficiently close for all practical purposes and is read as follows:

Suppose the head on the crest is $11\frac{5}{8}$ inches and the weir is 6 feet wide. In the table opposite $11\frac{5}{8}$ will be found 192.2, which is the cubic feet discharge for a weir 1 foot wide; this multiplied by 6 gives the discharge for the above example (1153.2 cubic feet).

If a more accurate measurement is desired the following formula should be used:

$$Q = 3.33\ (L - .2\ H)\ H^{\frac{3}{2}}.$$

L = length of weir in feet.
H = head, in feet, on crest.
Q = cubic feet of water per second.

Flow of River. In order to calculate the amount of water flowing in a large stream or river in all seasons observation stations have to be established. These stations are nothing more than a gauge-rod so set that the height of the water can be easily read. In order to assure a true record of the volume of water flowing it is essential to establish such stations on the main stream and tributaries. The levels must be read every day for a number of years, and during the flood season they must be read two or three times during the day and the average taken. From the observations of the depth of water the area of the cross section of each portion of the stream considered as a number of superimposed horizontal layers is computed; the cross-section area of each assumed layer multiplied by the mean velocity of that layer gives

a partial discharge. The sum of the partial discharges is the total discharge of the stream.

At the several stations the flow of the river is measured and recorded by current meters, of which there are several on the market; Fig. 2 illustrates a type of same. On the bottom of the rod is a lead weight to keep the instrument in an upright position. The water flows against the buckets, and the number of revolutions is recorded by an electrical indicator.

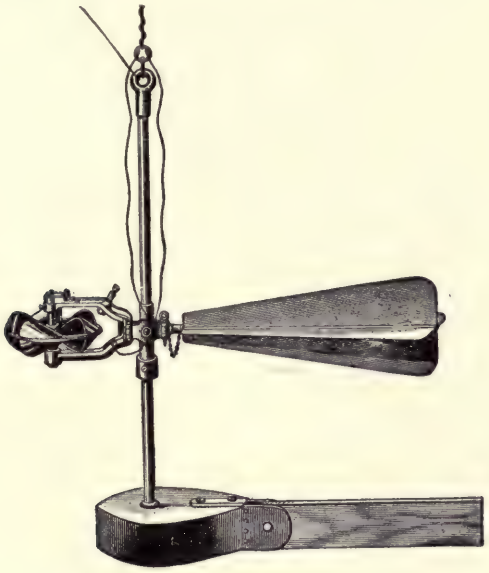


FIG. 2.—Current Meter.

A more primitive way to measure the velocity of a stream is given under Weir Dams; a more scientific way is by means of the Venturi meter. This meter was invented by Herschel in 1887,[1] and consists of a contracted pipe, with two gauges, one at the contraction and the other in the full size. When there is no motion of water in the pipe both gauges read alike; when the flow becomes sufficiently rapid, the gauge at the throat will indicate vacuum, while the other will continue to indicate the pressure due to head. From the difference in the two readings, and the constant of the meter, the velocity of the water through the throat can be computed. By applying a self-recording differential gauge the velocity and quantity of water may be registered.

Measurements of flow as outlined above are made to cover a considerable range of gauge height. They are then plotted on coördinate paper, with gauge heights for ordinates and discharges as abscissas, and a smooth curve, called the rating curve, is drawn through the points. From this curve a rating table is made which shows the discharge of the stream for any gauge height.

The data necessary for the construction of a rating table for a gauging station are the results of the discharge measurements, which include the record of stage

[1] Trans. Am. Soc. C. E., vol. 17, page 228.

of the river at the time of measurement, the area of the cross section, the mean velocity of the current, and the quantity of water flowing, and a thorough knowledge of the conditions at and in the vicinity of the station. The construction of the rating table depends on the following laws of flow for open permanent channels: (1) the discharge will remain constant so long as the conditions at and near the gauging station remain constant; (2) the change of slope due to the rise and fall of the stream being neglected, the discharge will be the same whenever the stream is at a given stage; (3) the discharge is a function of, and increases gradually with, the stage.

The plotting of results of the various discharge measurements, using gauge heights as ordinates and discharge, mean velocity, and area as abscissas, will define curves which show the discharge, mean velocity, and area corresponding to any gauge height. For the development of these curves there should be a sufficient number of discharge measurements to cover every known variation in the height of the stream. Fig. 3

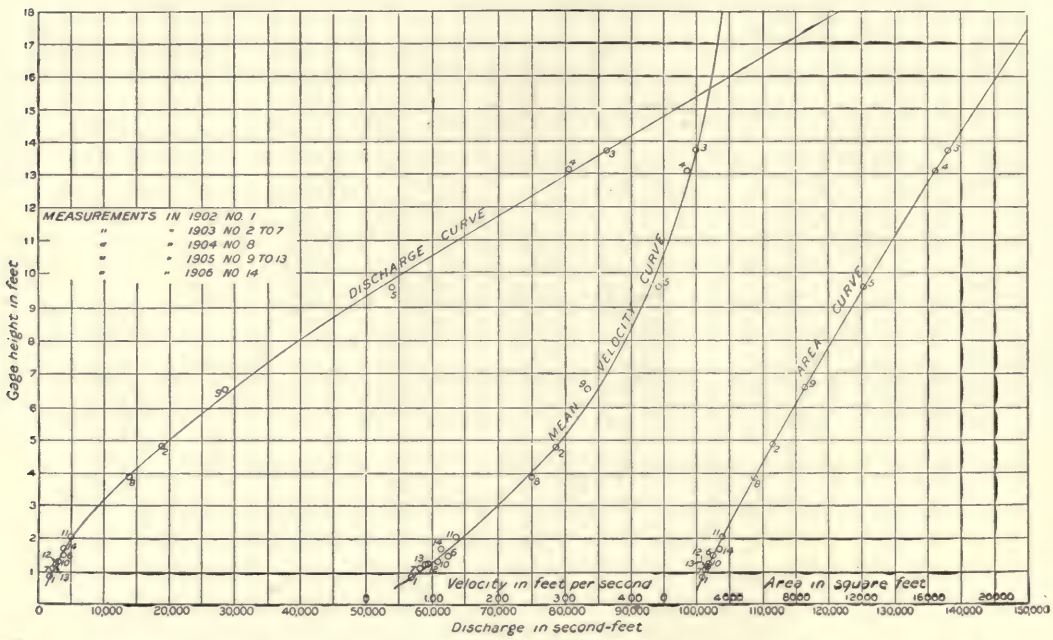


FIG. 3.—Method of Plotting Curves for Discharge, Mean Velocity and Area of Rivers.

shows a typical rating curve with its corresponding mean velocity and area curves.[1] As the discharge is the product of two factors, the area and the mean velocity, any change in either factor alone will produce a corresponding change in the discharge. The curves are therefore constructed in order to study each independently of the other.

The area curve can be definitely determined from accurate soundings extending to the limits of high water. It is always concave toward the horizontal axis or on a straight line unless the banks of the stream are overhanging.

[1] Water-Supply and Irrigation Paper No. 192 of the U. S. Geological Survey.

The form of the mean velocity curve depends chiefly on the surface slope, the roughness of the bed, and the cross section of the stream. Of these the slope is the principal factor. In accordance with the relative change of these factors the curve may be either a straight line, a curve, convex or concave, or a combination of the three.

From study of the conditions at any gauging station the form which the vertical velocity curve will take can be predicted, and it may be extended with reasonable certainty to stages beyond the limits of actual measurements. It is used principally in connection with the area curve in locating errors in discharge measurements and in constructing the rating table.

The discharge curve is drawn from the measurements of the discharge. The curve may have certain of its points located between and beyond those given by the actual measurements by means of the curves of area and mean velocity. Under normal conditions the discharge curve is concave toward the horizontal axis and is generally parabolic in form.

The chart is readily understood; the term "second-feet" is an abbreviation for cubic feet per second, and is the rate of discharge of water flowing in a stream 1 foot wide, 1 foot deep at the rate of 1 foot per second.

Profile of River. To ascertain the slope or fall of a river, elevations of the river level have to be read and plotted, so that the best locations for dams can be seen, see Fig. 4. The abscissæ give the distance in miles and the ordinates give the elevations in feet; the latter are preferably read as elevations above the sea level.

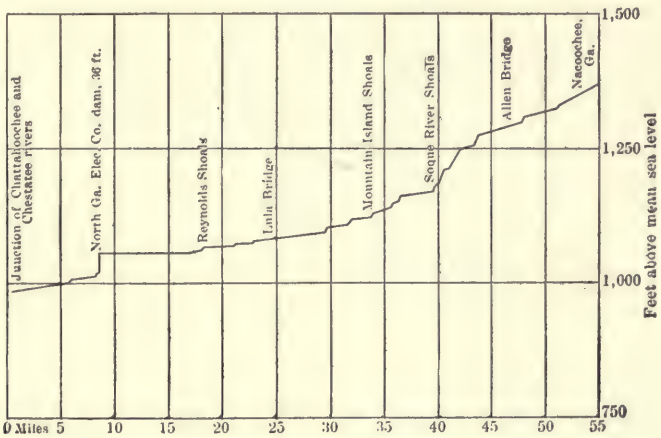


FIG. 4.—Method of Plotting River Bed. (Alcoy River.)

Government Reports. The governments of nearly all countries maintain departments for studying the flow of streams, and official reports on stream measurement are regularly issued. The United States Geological Survey has for more than twenty years been studying the various phases of the water resources of the United States. The results of most of these studies have been published as Water-Supply Papers. Some, however, appear in annual reports and bulletins. These studies

include measurements of the flow of streams, determination of river profiles, and collection of data in regard to water-power development.

These data give the records for a number of years of the rainfall, flow of streams in cubic feet per second for wet and dry seasons, and in some cases give the gross horsepower which could probably be developed, and occasionally offer suggestions to the hydraulic engineer. An excellent example is taken from the introduction of "The Relation of the Southern Appalachian Mountains to the Development of Water Power."[1]

According to estimates made by the United States Geological Survey there is a minimum of about 2,800,000 indicated horsepower developed by the rivers having their head waters in the Southern Appalachian Mountains. Mature consideration of the condition leads the Survey to estimate that at least 50 per cent and probably much more of this indicated power is available for economic development. If auxiliary power were provided, it would be profitable to develop up to 2.5 times this amount.

Full development of storage facilities would increase the minimum from 2 to 30 times. Obviously an estimate of present value based on 50 per cent of the minimum indicated horsepower is sure to be extremely conservative. The rental of 1,400,000 horsepower at $20 per horsepower per year would amount to an annual return of $28,000,000. This amount is equal to a gross income of 3 per cent on a capital of about $933,000,000. Some of this power has already been developed, but a very small proportion — hardly enough to make any appreciable showing when the enormous resources of the region are taken into account.

It has been estimated that in the United States more than 30,000,000 horsepower are available, and under certain assumptions as to storage reservoirs this amount can be increased to 150,000,000 horsepower or possibly more. In an address at the conference on the "Conservation of the Natural Resources," at Washington, D.C., May, 1908, St. Clair Putnam made the following statement on the value of the water powers in the United States:

"Using the smaller figure of 30 million horsepower as an illustration; to develop an equal amount of energy in our most modern steam electric power plants would require the burning of nearly 225,000,000 tons of coal per annum, and in the average steam engine plant, as now existing, more than 6,000,000 tons of coal, or 50 per cent in excess of the total coal production of the country in 1906. At the average price of $3.00 per ton, it would require the consumption of coal costing $1,800,000,000 to produce an equivalent power in steam plants of the present general type."

Of this immense water power available, only a small percentage is developed, estimated to be about 3,000,000 horsepower.

Nearly every state in the Union has large water powers available. It has been estimated that the upper Mississippi and its tributaries have an available water power of about 2,000,000 horsepower; that of the Southern Appalachian region, about 3,000,000; and that of the State of Washington alone, about 3,000,000 horsepower.

[1] Forest Service, Circular 144, U. S. Department of Agriculture.

ECONOMY IN DEVELOPMENT.

Preliminaries. The first cost, efficiency, and economy of an hydraulic development depend primarily on the ability of the designer. This fact, although of great importance, is often overlooked by the investors.

When a plant is to be built for a railroad company or other large corporation, the designer is frequently in the employ of the company; sometimes contracts are let to firms of contracting engineers, who may furnish the plans only or both the plans and the entire plant.

Contracts may be made between investors and engineers for professional services for specific amounts, or for a percentage plus disbursement, or for fixed sum plus disbursements. Capitalists or corporations, before letting contracts, should make thorough investigations, not only of the financial and business reputation of consulting and contracting engineers, but should convince themselves of the ability of the firms and their staffs, particularly of the designer in charge. Frequently during the course of construction or after the completion of a plant, an experienced designer shows where thousands of dollars could have been saved by engaging engineers who are specialists in the design of plants.

Reports made on plants after their construction have shown in some instances that in stations of 10,000 K.W. capacity several hundred thousand dollars could easily have been saved; while on plants of 50,000 K.W. capacity reports have been made showing where over a million dollars could have been saved.

Problems Involved. The problems involved in the design of hydroelectric plants are those of first cost of construction, equipment, operation, and maintenance.

It is the ultimate aim to produce electricity at a minimum of expense. To accomplish this end, experience is necessary. It is not the province of the engineer as a designer of hydroelectric plants to design any particular machine, such as turbines, generator, oil-switches, etc., but to provide a selection of different makes, each designed to perform its function in the most economical manner; and to have these machines properly combined to form one complete unit for the purpose of generating electricity from water on a satisfactory commercial basis. Since on the original design depends the economical operation of the plant, great care and foresight must be exercised in the selection and arrangement of the devices; for instance, a turbine for low head would not be so efficient if connected to a high head, and vice versa. The location of the power plant building must be chosen so as to obtain the greatest head with the least expenditure for head or tail race. As a general rule, the higher the head the cheaper will be the installation.

In designing a plant, and in the selection and arrangement of the equipment, some originality should be exercised. No designer should unreservedly copy the scheme of an existing plant, since what might be economical in one would possibly be the reverse in the other. Any attempt to standardize the design of hydraulic plants is practically impossible. However, in the design of a single station, a system of standardization must be adopted to minimize expenses in design, construction, and operation.

The work embodied in a complete installation comprises hydraulic, mechanical, structural, and electrical work. They are necessarily closely allied, and it is essential that the design of the entire undertaking be placed under one engineer. If this method is not followed, confusion may possibly result, delaying the work and incurring additional expense. If the work is divided among several designers, complete coöperation may not exist, and the various designers will probably conflict with one another; for instance, the same article or work may appear in two or more drawings or specifications, or may be entirely omitted, one designer considering it a part of another's work.

Designing Staff. Having secured the necessary data, and fixed the size of the plant, the design must be carried on systematically. As the scope of power plant design is a broad one, it is necessary in large plants to employ assistants, designers, and draughtsmen.

For instance, in designing a 50,000 K.W. plant the designer's staff may consist of one assistant, who is familiar with the various branches required in the complete plant; four or five draughtsmen (assistant designers), who are experienced in the various branches previously mentioned. The hydraulic or mechanical designer should arrange the general scheme, such as arrangement of turbines and particularly the headrace and the foundation of the building; the electrical designer, the electrical layout, such as wiring and switchboard, etc., and will work in conjunction with the mechanical engineer to establish the size of the building. The structural design depends upon the data supplied by the mechanical and electrical engineers for the skeleton of the building, floor loads, roof trusses, etc. The structural engineer is often called upon to assist in the design of the gates and penstocks, also to design the high tension transmission towers.

Architects are seldom employed, as is evidenced from the severely plain power houses, of which there are numerous examples. However, in the last few years occasional plants have been erected indicating that architectural talent has been employed.

In order to bring about system and economy in the draughting department, a few tracers may be employed to do less important work, such as tracing and lettering. By shifting the tracers around, as necessity requires, they receive proper training and a general knowledge of the whole power plant construction. While the checking of all drawings is necessary, it is not feasible to employ a checker to verify drawings of all branches. While he may check the dimensions in conjunction with the designer of the individual features, it is impossible to find a checker to verify the design as is usually done in structural steel branches. Such checkers have to be familiar not only with the general scheme but with the detail of every feature employed in the design of the complete plant. Therefore the designers of the different branches should check each other's drawings.

Drawings and Specifications. For convenience of the draughting department and especially the field, all drawings should be standardized. Drawings larger than 24 × 36 inches are cumbersome and inconvenient for constructors. Multiplicity of drawings should be avoided. Drawings of the several branches must not

appear on one sheet, i.e., the structural steel must not be on the same sheet as the foundation work or part of same. It is common practice to begin the work after a few drawings which later undergo revision as construction proceeds. Unless a system of revision numbers is used, subsequent construction is seriously handicapped.

Duplicate sets of blue prints should be required from the manufacturers, one set for the office files, the other to be returned with indicated changes or approval as the case may be. All drawings, as well as incoming and outgoing blue prints, should be properly indexed on a two-card filing or other efficient system.

Before submitting plans and specifications to contractors for bids, they should be complete in every respect, in fact they should be working drawings. The specifications must be drawn up after the plans are finished or practically finished, and should be so drawn as to simplify and explain the plans.

Each contractor's specifications should start where that of the previous contractor stopped, so that the work will not overlap, or gaps be left. It is not infrequent practice by plant designers to consult engineering salesmen or manufacturers, from whom it is always advisable to secure specifications, and draw comparisons between the products of the various manufacturers.

As stated, specifications and plans have to be complete before they are submitted for bids, in order to minimize in extras.

Extras are usually overcharged, since it is to these that some contractors look for profit. For instance, the contract for structural steel may be let from preliminary drawings, on a per pound basis, say from three to four cents; when, however, the plans are worked out in detail, it will be found that there are a number of staircases, ladders, railings, etc., not shown in preliminary drawings, and the contractor, on a plea that more workmanship is required with this kind of work, will raise his price to seven or eight cents per pound or even more. For certain apparatus, such as turbines, generators, and overhead cranes, etc., preliminary bids may be asked for from rough drawings to ascertain the approximate cost of the plant. This may be necessary when the design is limited to a fixed sum.

Field Office. As most hydraulic developments, particularly those of large size, are far away from the main engineering organization, it is necessary to have an experienced and capable engineer with a good staff in the field. Cases always arise during construction where, for various reasons, the drawings cannot be strictly followed, and to secure the necessary instruction from the home office consumes much time and may cause confusion. Most of the errors discovered in the process of construction are trivial in themselves, but affect the remainder of the plant. Any modifications of the original drawings made in the field must be undertaken only by an experienced resident engineer, who must have sufficient authority from the head office. All field corrections, however, must be at once reported to the main office, so that corresponding changes can be made on the original design.

BIBLIOGRAPHY.

TREATISE ON HYDRAULICS. 1903. Mansfield Merriman.

HYDRAULIC AND HYDRAULIC MOTORS. P. J. Weisbach. Translated by A. J. Dubois.

A TREATISE ON HYDRAULICS. 1901. Henry T. Bovey.

HYDRAULICS. 1907. L. M. Hoskins.

RIVER DISCHARGE. 1907. J. C. Hoyt and N. C. Grover.

NOTES ON HYDROELECTRIC PLANT ORGANIZATION AND OPERATION. Farley Osgood. *Pro. Am. Inst. E. E.*, April, 1907.

CONSERVATION OF POWER RESOURCES. H. St. Clair Putnam. *Pro. Am. Inst. E. E.*, August, 1908.

WATER POWER DEVELOPMENT IN THE NATIONAL FORESTS. F. G. Baum. *Pro. Am. Inst. E. E.*, July, 1908.

SOME PRELIMINARY STEPS IN HYDROELECTRIC ENGINEERING. Frank Koester. *Electrical Review and Western Electrician*, Nov. 28, 1908.

RAINFALL OF THE UNITED STATES. A. J. Henry. Bulletin D, U. S. Weather Bureau, 1897.

RAINFALL AND FLOW OF STREAMS. C. C. Babb. *Trans. Am. Soc. C. E.*, vol. 28, p. 329, 1894.

THE INFLUENCE OF FORESTS UPON THE RAINFALL AND UPON THE FLOW OF STREAMS. G. F. Swain. *Jour. New Eng. W. Wks. Ass'n.*

DATA OF STREAM FLOW IN RELATION TO FORESTS. G. W. Rafter. Ass'n C. E. Cornell Univ., vol. 7, p. 22, 1899.

THE CONSERVATION OF WATER. John B. Freeman. *Proc. Am. Inst. E. E.*, March 24, 1909.

THE WASTES OF OUR NATURAL RESOURCES BY FIRE. Charles Whiting Baker. *Proc. Am. Inst. E. E.*, March 24, 1909.

ELECTRICITY AND THE CONSERVATION OF ENERGY. Lewis B. Stillwell. *Proc. Am. Inst. E. E.*, March 24, 1909.

CHAPTER II.

DAMS.

Gravity Dams. The fundamental principles on which the stability of a dam is calculated are given in the following formulas: First, it is essential to know the location of the center of gravity of a dam. This may be found for a dam of triangular shape, as it is indicated in Fig. 1. Assuming that the water behind the dam is even

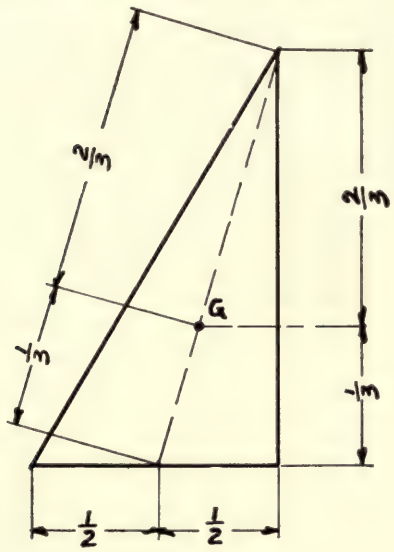


FIG. 1.

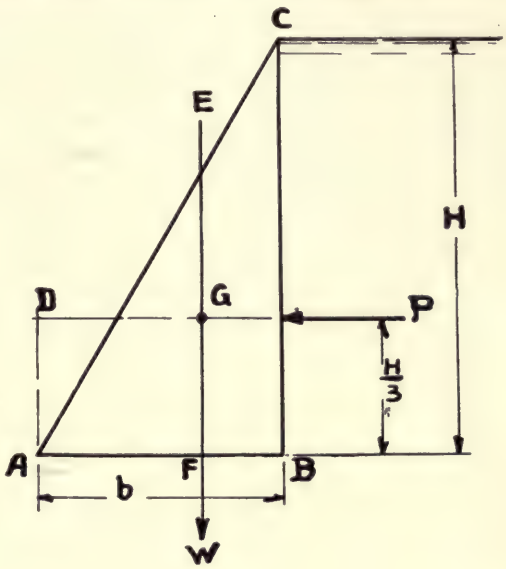


FIG. 2.

with the crest, as seen in Fig. 2, the pressure of the water against the dam is calculated in the following way:

H = head or height in feet.

P = total pressure of water in pounds.

$\frac{H}{3}$ = center of pressure.

W = total weight of dam acting through center of gravity,

$$= \frac{b \times H \times 1}{2} \times 140.$$

$$P = H \times 1 \times 62.5 \times \frac{H}{2}.$$

The pressure, P, acts perpendicularly to the face, and in turning the dam over uses the lever AD. The overturning moment is $P \times DA$.

To counterbalance the tendency of the water to overturn the dam, the weight of the dam acts through the lever AF. EF is drawn perpendicular to the base through the center of gravity. The resisting moment due to the weight of the dam is $W \times FA$.

$$\frac{W \times FA}{P \times DA}$$ is the factor of safety.

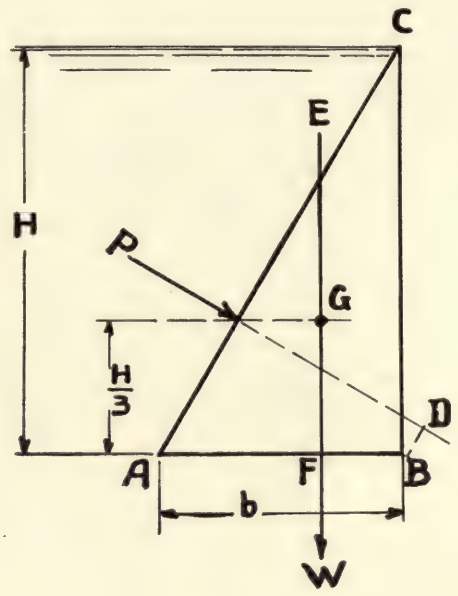


FIG. 3.

When the dam is turned around as shown in Fig. 3, the stability is calculated as follows:

The water pressure acts perpendicularly to the face CB, and the center of pressure acts on a line at the intersection of the slope and $\frac{1}{3}$ H.

The force, P, tends to overturn the dam about A with a lever arm DA, which is the perpendicular distance between the line of application of P and the point A. From this, it will be noticed, that the flatter the face CB, the less tendency the water has to overturn the dam.

$$\frac{W \times FA}{P \times DA}$$ is the factor of safety.

By examining the above fraction it will be seen that the factor of safety is increased. That is, as the dam is made to approach the gravity type, the overturning tendency of the water is diminished.

The above calculations are based on a theoretical dam, such as is never built, because it is impractical to build such a sharp crest, owing to the flow of water. In practice, gravity dams are built similar to Fig. 4; the center of gravity is found by laying off the breadth of the base on the slope side of the crest, and the breadth of the crest on the opposite side on the base; then draw a line connecting the points VV.

Draw a line from the middle of the crest to the middle of the base, connecting points XY. The center of gravity is located at the intersections of lines UV and XY. As gravity dams usually have water flowing over (Fig. 5), the following calculations

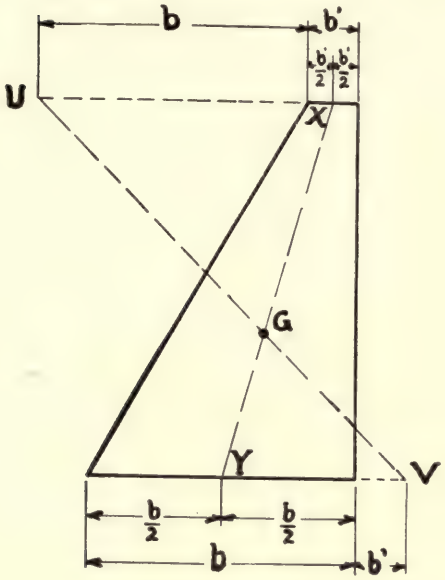


FIG. 4.

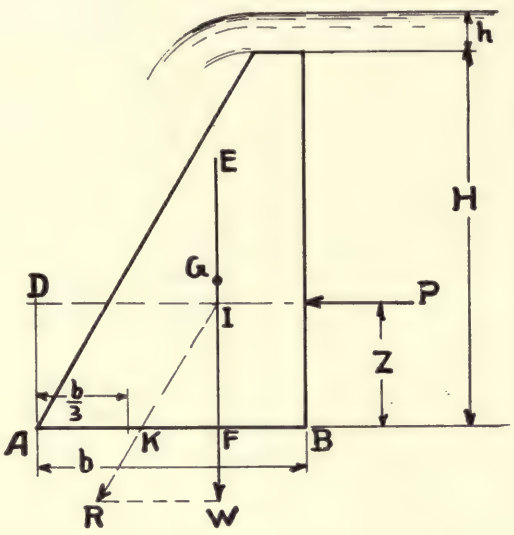


FIG. 5.

represent the conditions to be considered. The center of gravity is found as in Fig. 4. The vertical line EF is drawn through the center of gravity. The pressure P acts at point Z, and is located according to the formula

$$Z = \frac{H}{3}\left(1 + \frac{h}{H + 2h}\right).$$

The overturning effect of the water is the same as before, $P \times AD$. The dam counterbalances the overturning effect of the water with a moment, $W \times FA$.

$$\frac{W \times FA}{P \times AD} = \text{factor of safety.}$$

IR is the resultant of forces P and W, and is found by the application of paral lelogram of forces. IW is drawn proportional to the weight of the masonry, and WR is drawn proportional to the pressure of the water. To have the dam stable, the resultant, IR, must cut the base in some point as K, which must be at a distance greater than one-third the length of the base from the toe.

The downstream side or face of the spillway of the dam must be made to conform with the shape of the overflowing water, and in order to prevent erosion, the foot must be provided with a curved apron as seen in the accompanying illustrations (Figs. 6 to 8). This apron must be designed to withstand the effect of vacuum produced by the overflowing water.

Earthen and timber dams have long upstream faces, so that the tendency for the water to overturn them is greatly lessened, and are more fully treated under their respective sub-headings.

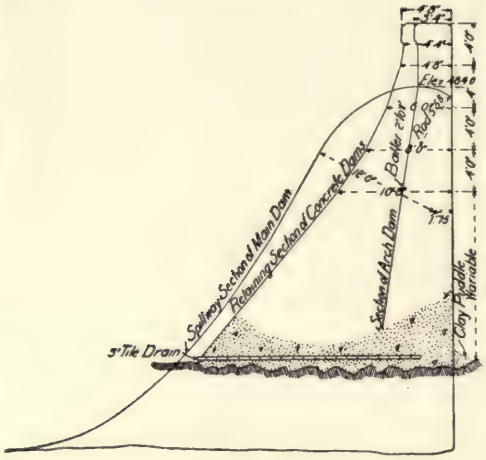


FIG. 6.—Cross Section of Dam (St. Louis River). Great Northern Power Company, Duluth, Minnesota.

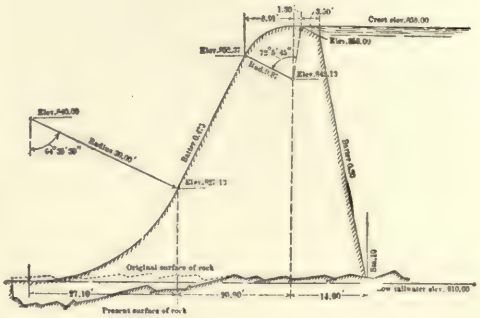


FIG. 7.—Dam at Morgan Fall, Georgia. Chattahoochee River.

Masonry Dams. Masonry dams are made either in the gravity or arch type. The stability of the straight gravity dam depends upon its own weight, while that of the arch type depends upon the thrust action at the ends, which rest on the mountain slope.

All gravity dams must rest upon very solid foundations. Where this condition cannot be obtained, an artificial one must be made, which can be done, for instance, by driving wooden, concrete or iron sheet piles. Where a rock bed is found, the bed must be cleaned of all earth and loose boulders, and provided with trenches to increase the resistance of friction by sliding. The bottom of the dam should extend some five or six feet below the river bed to prevent the water from leaking under, which might make the dam fail.



FIG. 8.—Dam at Spier Fall, Albany. Hudson River Electric Power Company, New York.

The majority of masonry dams are made of solid concrete or of cyclopean masonry (Fig. 8). The mixture used in concrete dams is 1 : 3 : 6 or 1 : 4 : 8, depending greatly upon the size of the dam. Frequently a coarser mixture is used, known as rubble concrete. In large hydraulic undertakings, particularly in the West, cyclopean masonry is employed; the stones vary in size from cobble-stones up to stones weighing one to two tons. The stones are so placed that the smaller ones fill up the places between the big ones, the whole being embedded in concrete mortar. Care must be taken in the construction of these, as well as other dams, to make them

A.E.&M.
UNIV. OF CA

as water tight as possible to prevent seepage. To accomplish this, the upstream side of the dam must be faced with a rich mixture of cement mortar or a finer course of concrete; sometimes tiles are used for facing. In addition to this, vertical drainage pipes are embedded in the concrete to carry off seepage. The pipes, usually 4 inches in diameter, are set in vertical sections, with space between, so that the seepage can enter same, and join mains which discharge on the downstream side.

Reinforced Concrete Dams. In the last five or six years, the reinforced concrete dam has been much favored for hydroelectric plants. The design is specialized and involves striking features of the adaptability of reinforced concrete. The principle, which these designers of dams endeavor to preserve, is, that the water pressure applied to a dam renders it not less but more stable, that is, the vertical component of the static pressure is made use of to pin the dam to its foundations, whereas, with the previously discussed masonry gravity dams, the pressure of the water is exerted horizontally (provided the upstream side is vertical) to overturn the dam, which must therefore be made sufficiently massive to resist the pressure by its own weight. The pressure exerted on the foundation of a gravity dam varies, theoretically, from zero at the upstream edge to a maximum at the downstream edge. The maximum must never exceed the crushing strength of the material. Usually a factor of safety of 2 or $1\frac{1}{2}$ is employed.

The slope of the "deck" of a reinforced concrete dam may be so related to the weight and width, that the pressure on the foundation is controlled at the will of the designer.

Usually the proportions are such that the diagram of pressure is nearly a rectangle; i.e., the pressure is kept substantially uniform over the whole foundation, and with the excess pressure, if any, thrown slightly towards the upstream angle instead of being concentrated at the downstream edge. This arises from the fact that the resultant of the water pressure and weight of the dam can be held at, or a little above, the center of the base, instead of passing down to the lower edge of the middle third. The movements of this resultant and the base pressures dependent thereon may be followed in the diagram, Fig. 9, in which the resultant, as the dam fills, is seen to advance slightly upstream from the center, until the dam is about three-quarters full, returning again nearly to the center, when the dam is under its calculated flood. The angle of the resultant also is always kept within the limit of the angle of friction, so that the dam has no tendency to move on its base.

Fig. 10 shows about the simplest form of dam adapted to moderate heads and hard foundations. It consists of a series of buttresses variously spaced from 12 feet to 18 feet apart on centers, and covered with a deck of concrete, reinforced between the different bays as a beam after the usual formula. The factor of safety throughout is said to be never less than 5 in all its relations. But little reinforcement is used in the buttresses, except at the edges and around the openings, which are left for convenience and to save material. The deck reinforcement, however, is abundant, and is within $1\frac{1}{2}$ inches of the lower side, leaving from 10 inches to several feet of concrete between the steel and the water. The thickness of the deck necessarily increases from top to bottom with the increase of head. The concrete in the deck is mixed

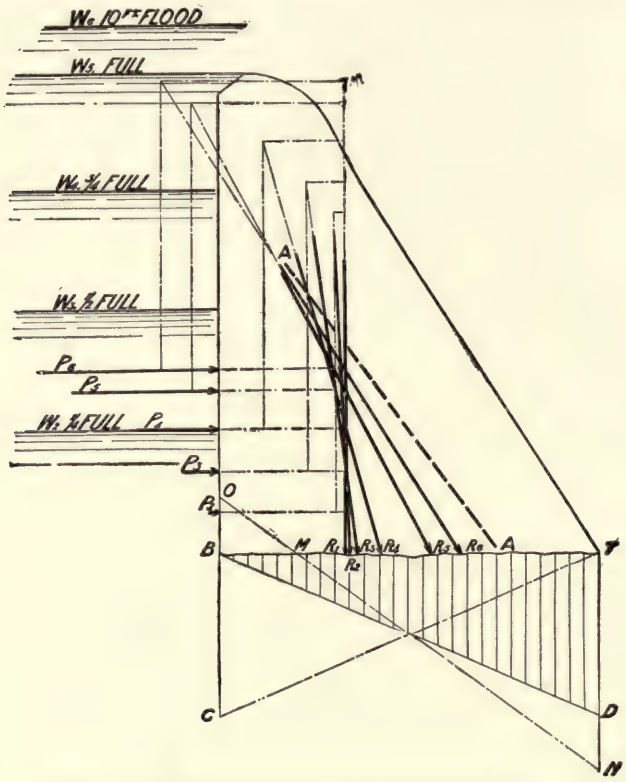


FIG. 9.—Behavior of Resultants in Solid Dam.

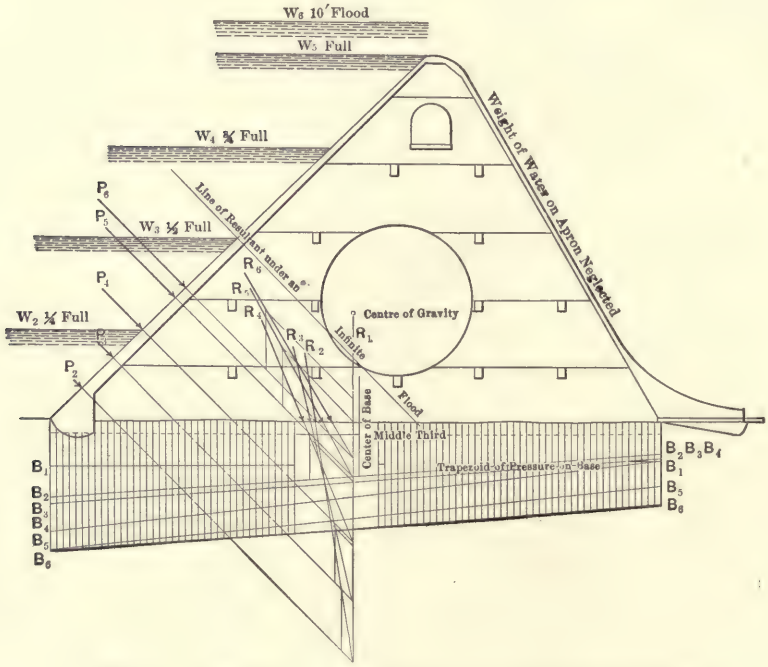


FIG. 10.—Behavior of Resultants in a Concrete-Steel Dam.

1:2:4, usually with fine aggregates, and is poured into the forms in the condition known as "slop concrete." This insures a thorough coating of the steel with cement, and furthermore, insures a density of concrete which seems to be sufficient to forestall porosity altogether.

A dam of this design, when on rock, has no continuous base, and therefore cannot be threatened by water pressure finding its way through seams in the rock, and exerting a lifting pressure on the dam. On gravel or other porous foundations, an artificial base is first laid down covering the entire area, but in such cases, this base or floor is pierced with numerous "weep holes," so that upward pressure is again forestalled.

Being hollow, reinforced concrete dams not only possess the unusual feature of interior inspection, but the hollow space puts at the disposal of the engineer a valuable space from which to work the various adjuncts, such as flashboards, waste gates, log sluices, movable crests, etc., all of which are handled from the inside of the dam, allowing the whole width of the river to be utilized for rollway, instead of being more or less obstructed by bulkheads. The interior of the dam admits of plenty of space for a passageway, which may vary from an ordinary foot bridge to the equipment of a complete power plant as seen in Fig. 11.

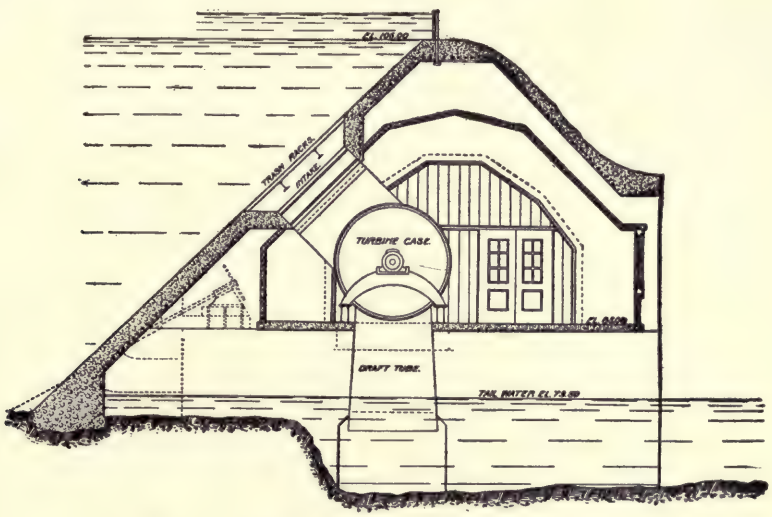


FIG. 11.—Patapco Dam, Ilchester, Maryland.

The spacing of the piers, which leaves a free waterway, often enables this type of dam, on certain foundations, to be built without the use of a coffer dam, by first carrying up piers in caissons to a uniform grade a few feet above the ordinary water level, and then completing the superstructure while the water is allowed to run freely between the piers. When the dam is completed, these spaces are subsequently and permanently closed with concrete.

Referring to Fig. 11, this dam, 200 feet long and 30 feet high, is located near Ilchester, Md., and crosses the Patapsco River. The power house is located inside,

and is equipped with three 500-HP. turbines, provided with draft tubes extending vertically into the tailrace; the generators are direct connected to the turbines; the switchboard and other electrical equipment are also located inside, so that the whole plant is housed inside of the dam. As this plant has been in operation for some time, no trouble has been experienced due to moisture; however, the power house itself is inclosed with four-inch walls of ferro-inclave, entirely separate from the structure of the dam itself.

Another power plant, where a reinforced concrete dam has been employed, is given in Fig. 12, showing the general arrangement of dam, forebay and power house, of the Bar Harbor and Union River Power Company, Ellsworth, Me. The dam is 450 feet long and 64 feet high. The conditions were such, that a semi-attached power house was necessary at right angles to the dam, and necessarily supplied from a forebay. Access to the power house and waste gates may be had through the body of the dam, which is entered on the opposite end from the power house. Part of the dam is utilized as a machine shop, storeroom, etc. A sluice gate in the crest is provided, to flush away the accumulated trash which may lodge against the dam. The details of construction of the dam are given in Figs. 13 and 14, and are self-explanatory.

This dam, as well as those above described, was constructed by the Ambursen Hydraulic Company, Boston, Mass., to whom the writer is indebted for data on reinforced concrete dams.

Coffer Dams. In most cases, when dams are built, coffer dams are necessary to hold back the water, so that the construction of the main dam can be carried on. The coffer dams are built so that a section of the stream or the entire river is deflected.

They are temporary constructions, and are removed after the main dam is completed. In shallow and still water, they may be built of gravel and clay, or bags filled with gravel and clay, or bundles of fagots, between which is placed gravel and clay. When the water is deeper and a current exists, this material is apt to be washed away; in such a case, sheet piling is used. Where single sheet piling is not sufficient to withstand the current, two rows of sheet piling are used, the space between being filled with puddle; this construction, of course, has to be properly braced, and, as it is composed mostly of wood, it is becoming very expensive; owing to this fact, it has been replaced in recent years by sheet steel piling. This sheet steel piling is made of rolled iron, such as Z-bars, channels, I-beams, and in some cases, specially rolled forms; they are so placed that they are interlocked and kept water tight. This system is very much favored, particularly in large construction work. They are easily driven home, and after the work is finished, they may be used again for other or similar purposes.

Crib Dams. Where the bed of the river is rock or near to it, the sheet pile coffer dam cannot be used; in place of it, the crib dam must be substituted. Before a crib is sunk, soundings must be made, to ascertain the contour of the bottom; in some cases divers are sent down. The lower part of the crib is made on shore and floated to the place where it is to be sunk, which is done by filling the same with rocks. As the crib sinks, the remainder of the crib is completed. These cribs are made in

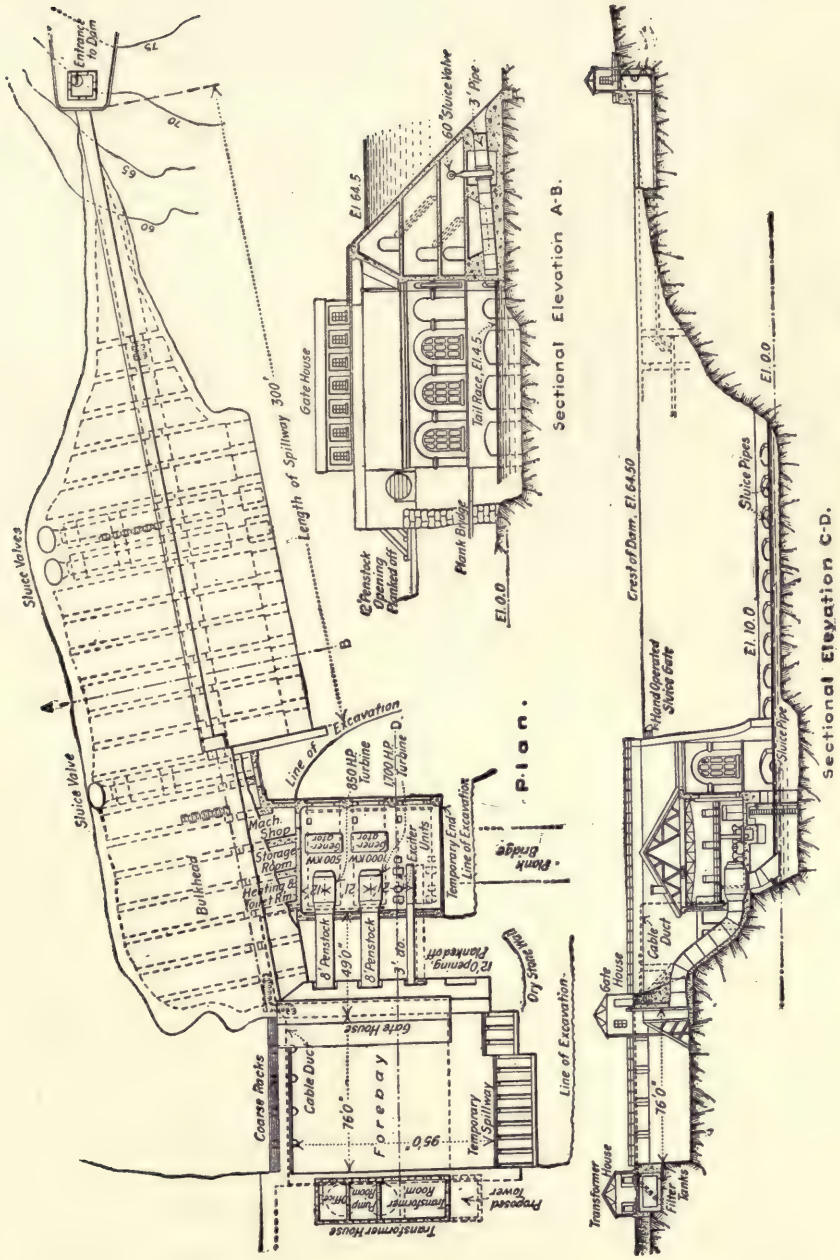
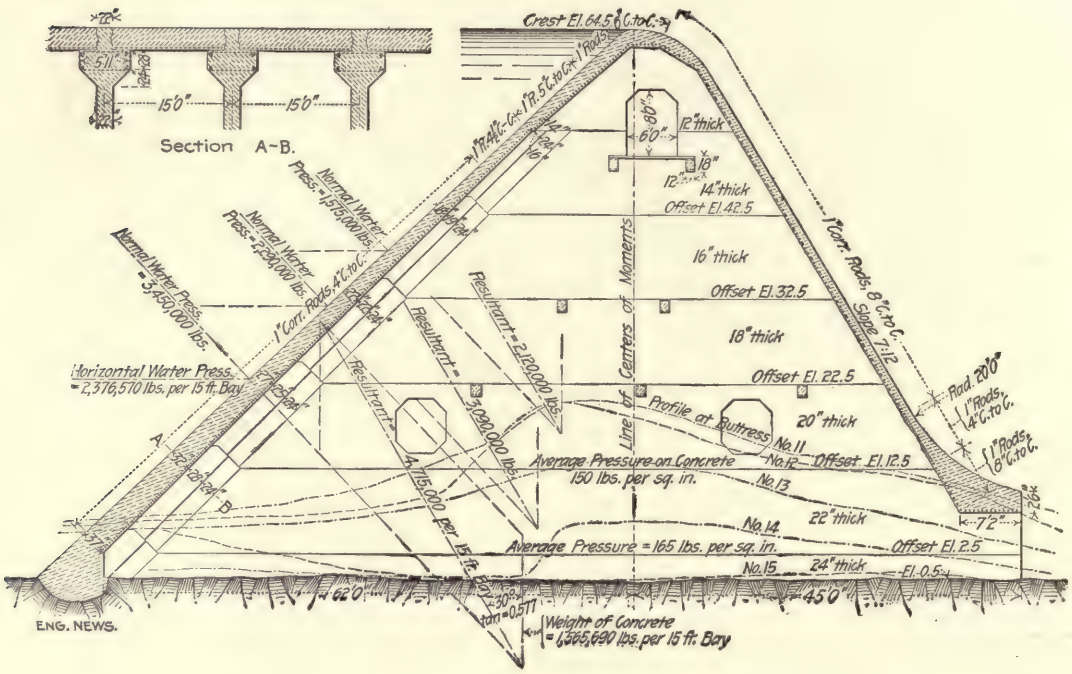
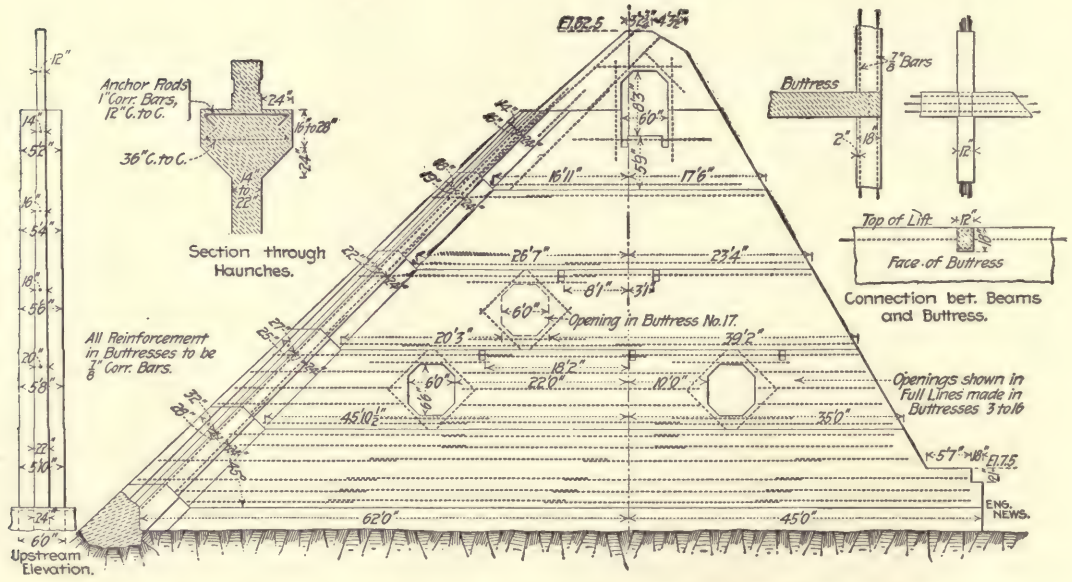


FIG. 12.—General Arrangement of Power Plant of Bar Harbor and Union River Power Company, Ellsworth, Maine.





FIGS. 13 and 14.—Detail Construction of Reinforced Concrete Dam at Ellsworth, Maine.

sections, about 8 to 10 feet square, and are grouped in width according to the height of the crib. The opening between adjoining cribs must be closed up by stop logs and timber sheeting.

The sheeting must be placed so as to break joints, and shaped to fit the profile of the river bed. For further tightness, riprap, sand and loam are dumped on the bottom of the upstream side of the crib.

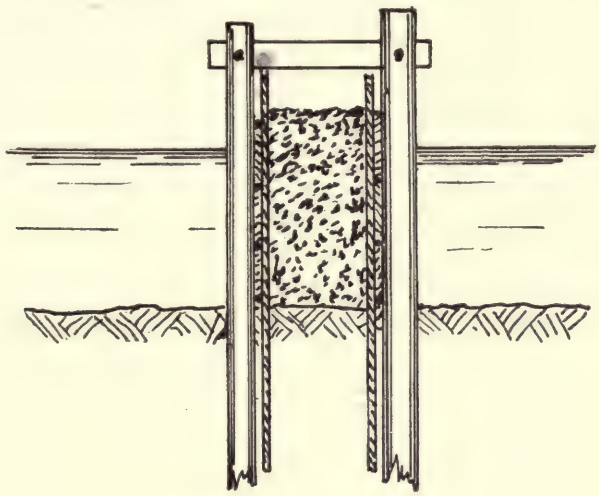


FIG. 15.—Coffer Dam.

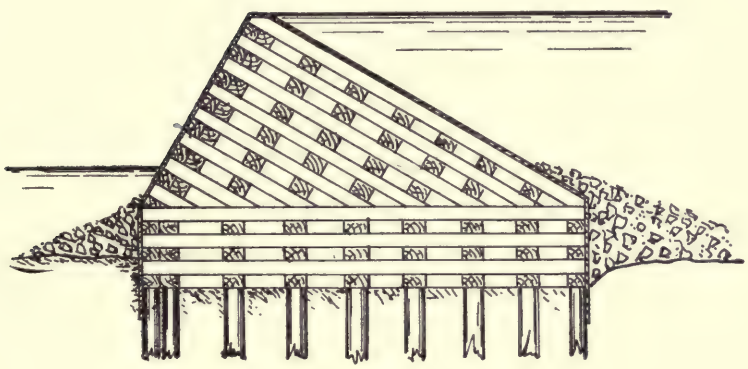


FIG. 16.—Timber Dam.

Timber Dams. In a timber gravity dam, the timbers are placed alternately parallel to and crosswise the stream, the spaces between being filled with earth and stone. The bearings of the timbers are either notched, or spiked by iron drift bolts. If the dam is built for retaining water only, the upstream side is built on a slope, while the downstream side may be vertical. If the water overflows the dam, the downstream side must be on a slope, in order to prevent the water washing away the river bed in front of the dam. There are several examples of failures of timber dams due to the erosion of the river bed. Trautwine states:[1] the Jones Dam at Cape Fear

[1] Trautwine, Civil Engineers' Pocket Book.

River had a height of 16 feet, and the usual water fall was 10 feet into a pool 6 feet deep, and in a few years wore out the soft shale rock, undermining the dam to such an extent that it gave way. The timber dam at Holyoke is another example of the erosion of the river bed due to the falling of the water, so that the dam had to be reinforced by a downstream apron.

The apron of the downstream side of the dam should be on an angle of about 30 degrees, so that the water has an easy overflow and protects the river bed.

There are other forms of timber dams, the frame types. They are built in framework of various forms, which vary according to conditions. The timbers are framed and strongly braced, upon the top of which is placed sheet planking. As they are lighter than the rock-filled timber dam, the upstream side must be on a longer slope, so that advantage may be taken of the weight of the water to secure greater stability. These dams are easily built, and in certain sections of the country they are the cheapest form for hydraulic power developments.

However, with the diminution of the forests and the cheapness of masonry and iron, the latter is more profitable to use.

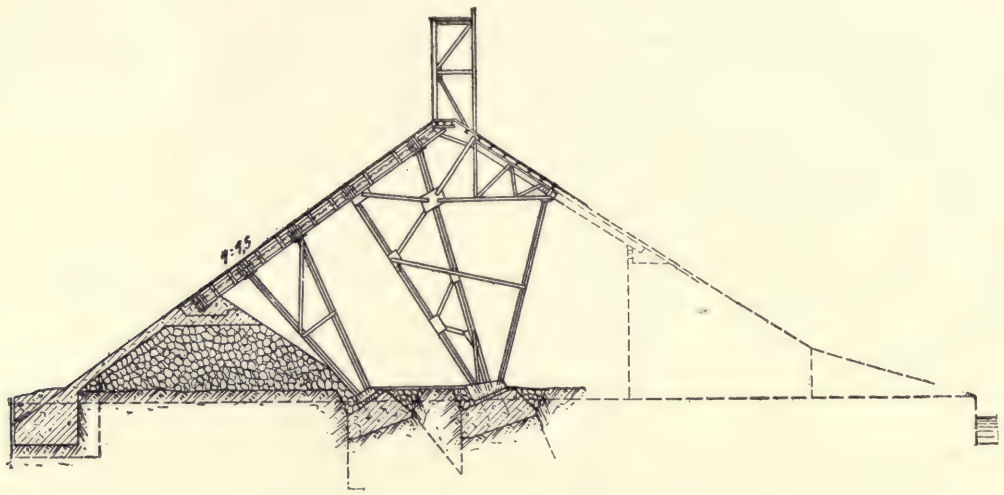


FIG. 17.—Hauser Lake Steel Frame Dam.

Steel Frame Dams. Similar in construction to the timber framework dam is the steel frame dam, as seen in Fig. 17. This dam has been erected by the Helena Power Transmission Company, across the Missouri River at Helena, Mont.[1] During a period of the year, about two to four months, it has to stand high floods and act as an overflow dam. It is about 75 feet high and 630 feet long. The lower section of the upstream side is of concrete, behind which is rubble masonry; the upper section is made of structural steel trusses 9 feet 9 inches apart. The entire upstream side is faced with steel plates; those on the bottom extend into concrete and fasten to sheet piling beneath the river bed, so as to prevent the water from washing beneath

[1] *Zeitschrift des Vereines deutscher Ingenieure*, April 18, 1908.

the dam. These, as well as those on the upper section, are flat plates, five-sixteenths of an inch thick, while the middle are concave and three-eighths inch thick. Only the upper section of the downstream side is faced with steel plates; the lower section is made of timber and faced with planking. On the top of the dam is a flashboard structure faced with steel plates at both ends, and in the middle is an opening 50 feet long to let through floods, and can be closed after the flood has passed.

This dam failed on April 14, 1908, and at the time of the accident, the matter of acceptance and final settlement was in the hands of the attorneys of the power company. The following is an abstract report given by the *Electrical Review*.[1]

"The initial break occurred at bent 39, about 400 feet from the east or power-house end of the dam. The anchorage at this point apparently gave way, breaking the seal, and allowing the water to pass under the rubble masonry fill. The water rapidly cut away the gravel, permitting settlement of this upstream masonry, and carrying down with it the lower end of the girder, forming the upper member of the steel bent. The expansion joint in this girder, and in the plates of the dam just above the top of the masonry, gave way, leaving the bents and plates unsupported in such a manner that the water pressure pushed over this section. About six minutes elapsed from the time the water first came through under the rubble masonry until the expansion joint failed and the first bent toppled over, carrying out a section about 30 feet in width. The tremendous rush of water rapidly widened the breach, the foundations on each side were undermined, and the posts and steelwork buckled at right angles to the direction of the flow of the river. The bents continued to give way and fall until the breach widened to nearly 300 feet."

Earth Dams. The earth dam is the oldest type of dam known, and is still used in hydraulic developments. They are made of loam, clay, and rock, or a combination of same. These dams are used principally in still water; however, if they are intended to be used as an overflow dam, they must be properly faced so that no erosion can take place. The upstream side usually has a slope of 2 : 1, while the downstream

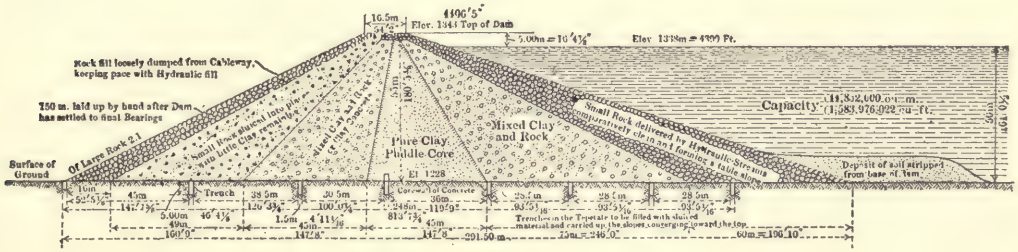


FIG. 18.—Cross Section of Necaxa Dam, Mexico.

side has the same slope or somewhat less, frequently $1\frac{1}{2}$: 1. These dams are sometimes sluiced into place. A dam built after this method is given in Fig. 18; it is that of the Necaxa Light and Power Company.[2] It is 180 feet high, 1276 feet long at the crest, and has a thickness of 950 feet at the base and 54 feet at the top. The

[1] *Electrical Review*, May 16, 1908.

[2] Trans. Am. Soc. C. E., vol. LVIII, p. 37, 1907.

slope on the upstream side is 3 : 1, and on the downstream side 2 : 1. The make-up of the dam is best shown in the cut, and consists of about 2 million cubic yards of material, which was obtained from the neighboring hills and sluiced into place.

The method of construction as given in a paper, "The Necaxa Plant of the Mexican Light and Power Company," by F. S. Pearson and F. O. Blackwell, is as follows:

"The ground was first cleared and stripped, a trestle to support the flume was erected, and low earth dikes were made at the upstream and downstream limits of the fill, to hold the mud and water. The material was then sluiced in, the pipes discharging near the embankments so that the boulders and gravel were deposited on the faces, and the fine mud in the center of the dam. The dikes were raised as the dam filled, and the water spilled over the upstream face into the pond. During construction the water of the river passed through the discharge gates, which were made large enough for the purpose. A spillway was provided over a neck of rock to the north of the dam."

For additional stability, the earth dam may be built with a concrete or reinforced concrete core. A dam of the latter type is at Dixville, N.H.[1] The core, 1 : 3 : 4 concrete, is 3 feet thick at the bottom and 10 inches at the top; it is reinforced by corrugated steel bars. Owing to the character of the soil the core rests on an interlocking steel sheet piling, which is driven at depths ranging from 10 to 32 feet, the entire length of the dam, the upper end being embedded into the concrete core.

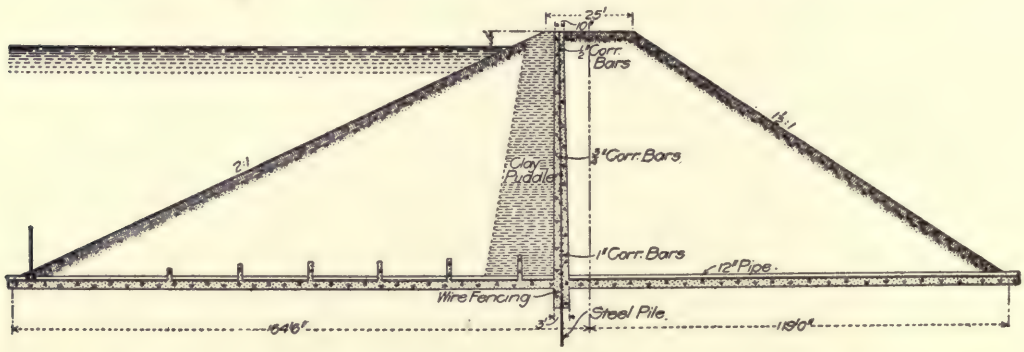


FIG. 19.—Earth Dam with Reinforced Concrete Core Wall, Dixville, New Hampshire.

Movable Dams. There are great variations in movable dams, such as sluice gate, drum and butterfly types, and common flashboards. They are used where a great fluctuation of water level is encountered, and are adapted to establish various heads. Probably the most prominent of this type of dam is the Stoney roller sluice gate, built in practically any size. These gates move in vertical grooves on roller trains in the abutting piers. The arrangement of the roller trains is such that the gates move twice as fast as the rollers, that is, the gates roll on the diameter of the rollers, and the rollers roll on their radii; both the rollers and the gates are counterbalanced, so

[1] An Earth Dam with Reinforced Concrete Core Walls at Dixville, N.H., by A. W. Dudley. *Engineering Record*, April 25, 1908.

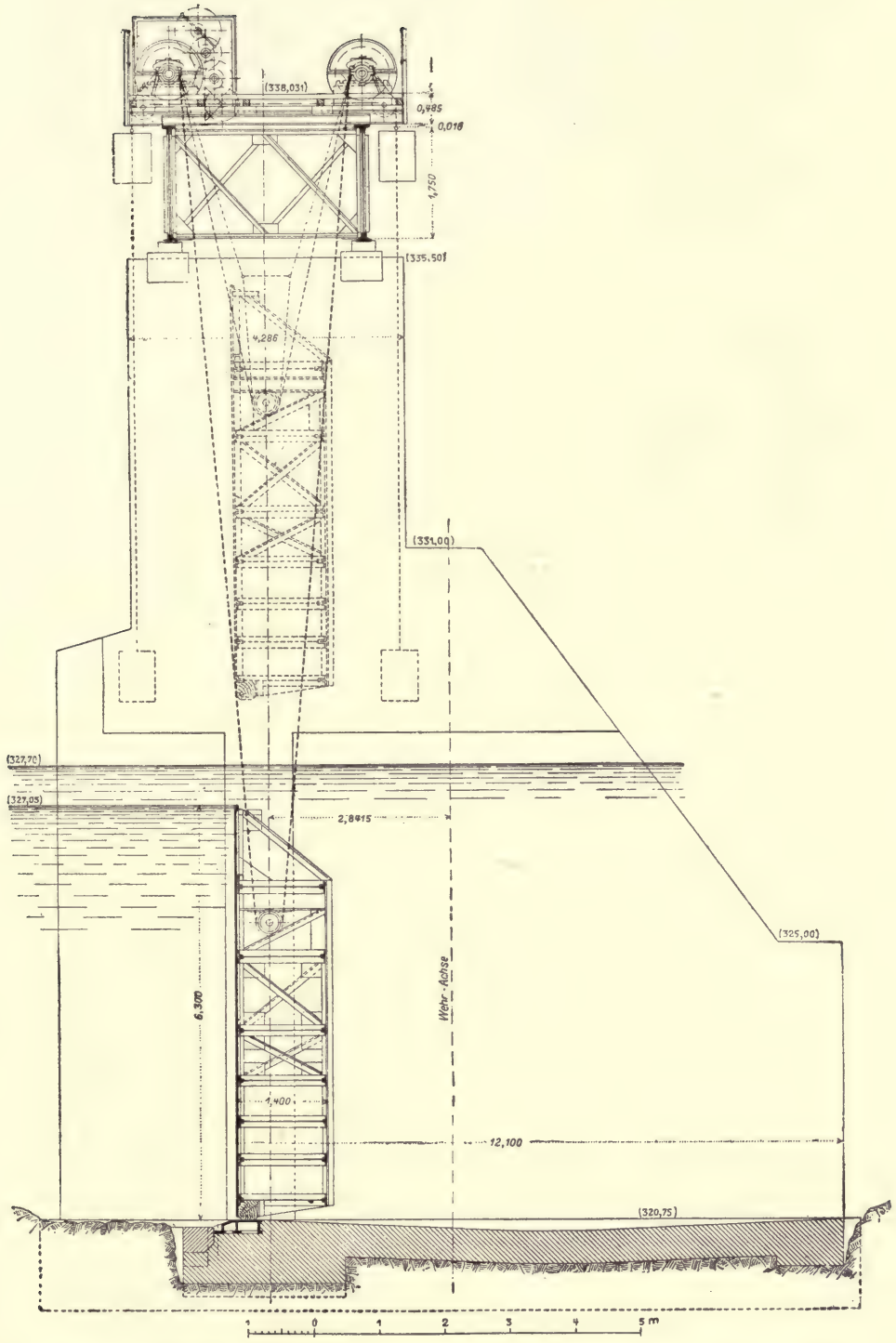


FIG. 20.—General Arrangement of Stoney Roller Sluice Gate, at Beznau Plant, Switzerland.

that a gate under a pressure of 300 or 400 tons can be easily moved by hand. A type of this gate is shown in Fig. 20, seven of which have been installed in connection with the Beznau plant, Switzerland.

These gates are 49 feet wide and 20 feet high; they are made of structural steel, and provided on the bottom with a square timber, resting on a cast-iron shoe embedded in the concrete of the dam. The sides of the gates are made water tight by steel ropes which are held against the joint by the pressure of the water (see Fig. 21).

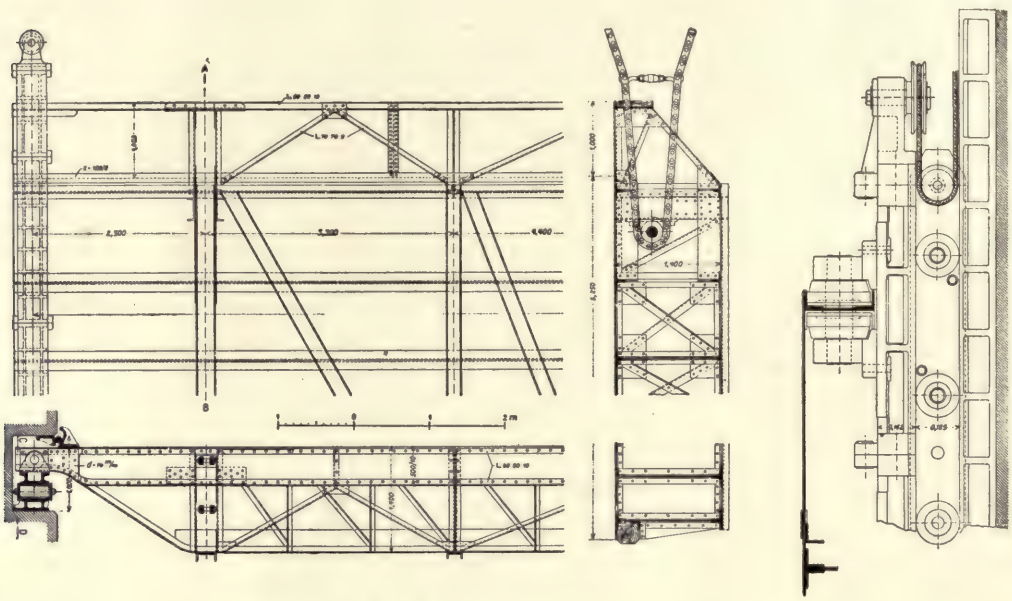


FIG. 21.—Details of Stoney Roller Sluice Gate.

Each gate may be operated by hand, two men being necessary, or for quick operation, there is a portable 8-HP. motor. Plans are at present in preparation for the installation of an hydraulic turbine at the dam, for automatically operating these gates in case of emergency. The discharge of the water from this type of dam takes place from underneath as the dam is hoisted; thus the foreign material which collects on the bottom is easily discharged.

Butterfly Dam. Another type of movable dam is the butterfly, an example of which is given in Fig. 22. Two of this kind have been installed in connection with the Chicago Drainage Canal,[1] one being 12 feet and the other 48 feet wide.

The two movable crest dams are practically alike in details of construction and operation. Each movable crest is built of structural steel shapes and steel plates, and is practically a 45-degree sector of a cylinder with a 26-foot radius. Each sector is hinged horizontally along the axis of the cylinder of which it would form a part, to

[1] Movable Crest Dams at the Water Power Development of the Chicago Drainage Canal. *The Engineering Record*, Aug. 24, 1907.

A.E.&M.E
UNIV. OF CA

the top of a back wall on which it is mounted on the downstream side. The radial deck plane and the curved upstream front of the sector are made water tight with steel plates, the deck being provided with steel angles for ice skids. The deck plane, the lower radial plane and the curved face are heavily reinforced by intermediate steel frames. When the crest formed by the intersection of the curved face and the radial deck plane is at the maximum operating height, the lower radial plane of the sector is horizontal. As the crest is lowered, the sector rotates on its axis and moves

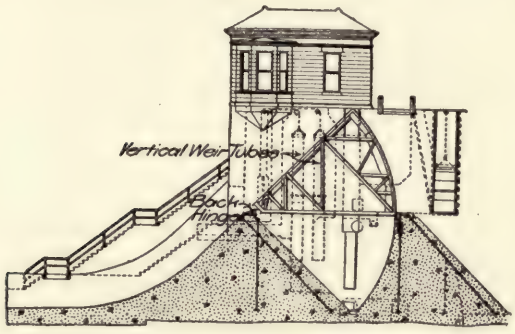


FIG. 22.—Butterfly Dam, Chicago. Drainage Canal Power Plant.

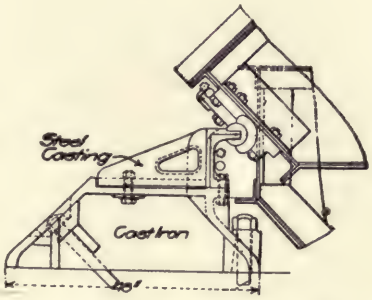


FIG. 23.—Detail of Back Hinge of Butterfly Dam.

into a space in the concrete base, which is also approximately a sector of a cylinder, of about the same radius as that of the crest, the radial deck being horizontal when the crest is at its lowest position. The crests of both dams have a vertical range of 18 feet, from 2 feet above to 16 feet below Chicago datum, the water surface above the dams being 4 to 6 feet below that level under normal conditions of flow.

Bear Traps. The old bear-traps consisted of two leaves, hinged to the foundations. The upstream leaf overlaps the downstream leaf when the gate is lowered. A culvert leaves from the river upstream, to the space under the leaves, and a second culvert from this space to the river downstream, and are provided with valves. When the first culvert is opened with the second closed, the hydraulic pressure under the leaves causes them to rise, provided the head from the upstream culvert is sufficient. Reversing the process, the leaves will fall.

The interior angle formed by the leaves in the raised position must not be less than 90 degrees, since, if it were, the trap when once up, would not fall under the action of the hydraulic forces. The angle should be about 100 to 105 degrees, and if the angle is too great, the width of the base will be excessive in proportion to the height of the crest above the foundations.

The principal defects of the old bear-trap, as given by P. S. Bond,[1] are as follows:

I. Sliding friction between the leaves.
II. Width of base too great for height attained.
III. The overlap of upper upon lower leaf.
IV. Inability to raise and fall uniformly (tendency to warp).

[1] The Permanent Improvement of the Ohio River. *The Engineering Record*, Jan. 16, 1909.

V. Necessity for initial head in raising.
VI. Difficulty of stopping without shock in raising.
VII. Difficulty of operation in wide passes, and division into several sections by piers.
VIII. Leakage at time of raising.
IX. Liability of binding on débris along side walls, and driftwood lodged in the exterior angle between the leaves.
X. Improper proportioning of leaves (unscientific design).
XI. Cost.

Many improvements have been made in late years, which relate more or less to the mechanical construction.

Cylindrical Dams. On the continent of Europe, several cylindrical rolling dams have been installed. Two prominent ones are located in the rivers Main and Sau at Schweinfurt, Bavaria;[1] the former is 13.5 feet in diameter and has a clear width of about 60 feet; the other one has a diameter of 6.5 feet and a length of 115 feet. It is practical to make them 39 feet in diameter and 150 feet span. These dams are nothing more than two concentric shells, the space between being air tight. The inner shell is open at the ends, so that when the dam is lowered, the water flows through, thus reducing the buoyancy effect. The dam is raised and lowered by a chain or cable wound around one end; both ends roll on cogwheel tracks.

The principal claims for this type of dam are, the elimination of piers in the center of a river, simplicity of construction in dam as well as machinery, and ease of operation. The dam may be easily raised above the river level, thus giving a free and unobstructed passage.

Needle Dams. A system for the temporary imponding of water is the needle dam, consisting of a row of squared timber or heavy planking set upright against a trestle. In case of excessive flood, a number are removed and the water released. As these needle dams are usually built across the entire width of the river, the trestle remains as an obstruction to floating material when any of the needles are removed.

Chanoine Dam. The objection in the needle dam mentioned is overcome in the Chanoine Dam, which can be lowered, thus giving free passage; it will tip automatically when the water rises to a certain height overflowing the crest, similar to permanent flashboards.

The movable parts of the Chanoine Dam consist of a row of wickets hinged on horses, and held in place by props. A detailed description of this system will be found in *The Engineering Record.*[2]

Flashboards. In order to take care of surplus water during flooding periods, or minimum use of water, flashboards are employed to impond water for dry season, or maximum demand. They are designed to withstand a certain amount of water, which would otherwise discharge over the dam; should the pressure exceed the designed limit, the supports give way and the boards are washed downstream;

[1] Wegmann, The Design and Construction of Dams.

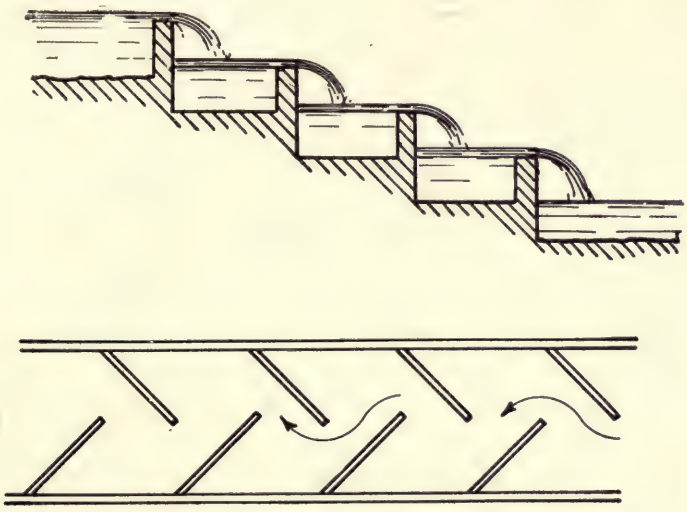
[2] Permanent Improvement of the Ohio River P. S. Bond. *The Engineering Record*, Jan. 9, 1909.

this of course in most instances would mean the loss of planking. However, in many instances, heavy floods are anticipated, and the flashboards are removed before the flood reaches its height.

Permanent flashboards are so arranged that part or the whole are removed, should the water rise above the limit. They may be built of structural steel; placed and removed from a footpath carried above the dam.

Another type of flashboard is of structural steel held in an upright position by rods hinged below the center of the board. When the pressure of the water above the hinge exceeds that exerted against the flashboard below the hinge, the flashboard drops over automatically; it is not washed away, but held by the anchor rods.

Fishways. Fishways are frequently required in connection with dams, in order to provide a passage for fish which return upstream to their breeding places during certain seasons of the year. In most countries, it is specified by the government whether they have to be installed or not; the size of these fishways depends upon the kind of fish and their habits; data on this subject can be obtained from the governments as well as local authorities.



FIGS. 24 and 25.—Types of Fishways.

These fishways are always located on one side of the dam, the outlets being at the bottom of the dam, because the fish usually gather there. The principle of a fishway consists in retarding the velocity of the water in an inclined trough provided with obstructions, so that the mean velocity will be no more than 6 or 8 feet per second, with resting places made by the nature of the obstructions. Such a passage, in most cases, is nothing more than a series of steps forming cascades, between which are pools of water as indicated in Fig. 25. Another form of fishway is seen in Fig. 26; it is nothing more than a chute which reduces the velocity of the water by the friction of a zigzag course. These fishways are made either of wood or masonry.

BIBLIOGRAPHY.

THE DESIGN AND CONSTRUCTION OF DAMS. Edward Wegmann. 1899. John Wiley & Sons. New York.

RESERVOIRS FOR IRRIGATION, WATER POWER AND DOMESTIC WATER SUPPLY. James Dix Schuyler. 1901. John Wiley & Sons. New York.

MASONRY CONSTRUCTION. I. O. Baker. 1903. John Wiley & Sons. New York.

NOTES ON STRESSES IN MASONRY DAMS. Max aus Ende. *Engineering*, Dec. 8, 1905.

INTERNAL STRESSES IN MASONRY DAMS. S. D. Bleich. *School of Mines Quarterly*, November, 1905.

RECENT PRACTICE IN HYDRAULIC-FILL DAM CONSTRUCTION. J. D. Schuyler. *A. S. C. E.*, October, 1906.

MASONRY DAMS. Th. G. Bocking. *Engineering*, Sept. 27, 1907.

MASONRY DAM FORMULAS. Orin L. Brodie. *School of Mines Quarterly*, April, 1908.

THE DESIGN OF BUTTRESSED DAMS OF REINFORCED CONCRETE. R. C. Beardsley. *Engineering News*, April 23, 1908.

A FORMULA FOR CALCULATING FLASHBOARDS FOR DAMS. Richard Muller. *Engineering Record*, Aug. 22, 1908.

THE DESIGN OF RETAINING WALLS. Harold A. Petterson. *Engineering Record*, June 13, 1908.

A PROPOSED NEW TYPE OF MASONRY DAM. Geo. L. Dillman. *Trans. A. S. C. E.*, vol. 49, p. 94, 1902.

THE CORRECT DESIGN AND STABILITY OF HIGH MASONRY DAMS. Geo. Y. Wisner. *Engineering News*, Oct. 1, 1903.

ON THE STABILITY OF MASONRY DAMS. Karl Pearson. Aug. 11, 1905.

ON THE DISTRIBUTION OF SHEARING STRESSES IN MASONRY DAMS. W. C. Unwin. *Engineering*, June 30, 1905.

THE STRESSES ON MASONRY DAMS. *Engineering*, September, 1907.

DESIGN OF AMERICAN DAMS. *Engineering Record*, Feb. 20, 1902.

THE LIMITING HEIGHTS OF EARTH DAMS. *Engineering Record*, Dec. 7, 1901.

EARTH DAMS WITH CONCRETE CORE WALLS. *Engineering News*, Sept. 7, 1905.

RECENT PRACTICE IN HYDRAULIC-FILL DAM CONSTRUCTION. *Proc. Am. Soc. C. E.*, October, 1906.

A COLLAPSIBLE STEEL DAM CREST. J. C. Wheeler. *Engineering News*, Oct. 3, 1907.

A NEW AUTOMATIC MOVABLE DAM. *Engineering Record*, March 8, 1902.

MOVABLE DAMS. B. F. Thomas. *A. S. C. E.*, March, 1898.

AMERICAN TYPES OF MOVABLE DAMS. Hiram M. Chittenden. *Engineering News*, Feb. 7, 1895.

MOVABLE DAMS, SLUICE AND LOCK GATES OF THE BEAR-TRAP TYPE. Archibald O. Powell. *Journal Association Engineering Societies*, June, 1896.

CHAPTER III.

HEADRACE.

Scheme. The arrangement of headrace is governed entirely by natural conditions. While some plants require a dam only, for securing water supply, others require in addition, miles of headrace, including expensive tunneling and installation of high-pressure penstocks. These are the extremes between high and low head plants. The ultimate aim in both cases is, to secure the greatest amount of energy with least expenditure both in first cost and cost of operation. Therefore, the building containing the turbines should be located so as to utilize the most efficient head. In some cases, tailrace water is discharged directly into the headrace of a plant located below.



FIG. 1.—Typical General Arrangement of a Hydroelectric Development.

Fig. 1 illustrates a way of harnessing a stream and conducting the water to the power house, or, in short, a complete hydraulic installation. In connection with same, the tailrace of a previously installed plant is utilized. This particular plant has been selected because it contains most of the features to be met in harnessing

water for hydroelectric developments. It utilizes the water of the river Sill, and supplies the capital of Tyrol, Innsbruck, with light and power.

In the illustration, the letter *C* designates the tailrace of a 6000-HP. plant, *a*, which joins the headrace at the sluice gates *h*; *g* are sluice gates to control the water in the river; *e* is a spillway dam; *f* and *f* represent racks; one prevents foreign material from entering the entrance basin from the river, and the other, a finer one, prevents material from entering from the headrace. At the lower end of the entrance basin is a sandtrap designated by *k*; there is also a sandtrap *k* at the side of the sluice gate *l*, before the water enters the tunnel; *i* is a spillway in the flume to discharge surplus water. The letters *m* designate shafts leading to the headrace tunnel, which is 4.7 miles long. There are seven shafts in all. The tunnel has a slope of 1 foot in 1000. It takes one hour for the water to travel from the entrance basin to the collecting reservoir. The letter *n* is an overflow wall in the reservoir, while *p* is a sluice for emptying same.

The water is discharged down the mountain slope, in cascade to break the fall, and joins the tailrace *n*. As the plant is located in a district of frequent and heavy snowfalls, a snow sluice *o* is provided. The water, before entering the penstock *r*, must pass through a fine screen *f*, then through a sluice *g*.

While the velocity of the water in the tunnel is 7.4 feet, the velocity in front of the screens, before entering the penstocks, is only 1 foot per second. At the bottom of the screen, which sets on the skew, is another sandtrap which discharges into the cascade.

It will be noticed that there is only one penstock *r* in place, to supply three units; it is about 11,000 feet long, and laid on the mountain at an angle of 33 degrees. The head is 602 feet to the center of the turbine shaft. As the friction loss is 5.5 feet, the effective head is 596.5 feet.

The penstock is made up of steel plates in sections, and the diameter is 4.1 feet, the upper section being of five-sixteenths material, and the lower section thirteen-sixteenths inch.

The turbines are of the impulse type, mounted in pairs on one shaft; when running at 350 R.P.M. and with an efficiency of 80 per cent they develop 2500 H.P., and consume 45.4 cubic feet of water per second.

CONDUITS.

Water may be conducted by the following methods:

1. Canals.
2. Tunnels.
3. Penstocks.

The canals may be subdivided into trenches and flumes.

The tunnels may be non-pressure and pressure.

The penstocks always operate under pressure, and may be built of steel, wood or reinforced concrete.

Cross Section of Canals. The cross-section area of a canal, may it be a trench or flume, should be such that the water will rise to about three-quarters to seven-

eighths of the height, but should never be higher than the latter. The rectangular form is the most common one in use, and is so proportioned that the depth of the water is about half of the width. The slope of the canal depends on the degree of smoothness of the bottom, and varies from one-half to one foot in a thousand; the latter is more common.

Trenches. The most common form of canal is an open trench dug in the soil, and the sides sloped according to the firmness of the soil, usually 1 : 1. If loose soil is encountered, the form of the canal must be such that the velocity is about 2 to 3 feet per second. If a higher velocity is taken, the sides and bed will be disturbed. If good loam is found, the velocity may be taken as 4 feet per second. This may be increased to 4.5 to 5 feet by lining the sides and bottom with paving stone and gravel.

According to Bazin's formula, the bottom and mean surface velocity may be found as follows:

$$v = \text{max. } v - 25.4\sqrt{rs};\ v = v_b + 10.87\sqrt{rs};\ \therefore v_b = v - 10.87\sqrt{rs}.$$

v = mean velocity in feet per second.

max. v = maximum surface velocity in feet per second.

v_b = bottom velocity in feet per second.

r = hydraulic mean depth in feet = area of cross section in square feet divided by wetted perimeter in feet.

s = sine of slope.

The lowest velocity is found in the wetted perimeter. The different velocities, according to Rankine, are in the ratio 2 : 3 : 4 in low-velocity canals, and 3 : 4 : 5 in high-velocity canals. The greatest velocity is found in the middle slightly below the surface.

Ganguillet and Kutter give the following table I, of safe bottom and mean velocities in channels, calculated from the formula,

$$v = v_b + 10.87\sqrt{rs}.$$

The results obtained by using this formula are very low, as admitted by the above authorities.

TABLE I. — WATER VELOCITY IN CHANNELS.

Material of channel.	Safe bottom velocity (v_b) in feet per second.	Mean velocity (v) in feet per second.
Soft brown earth	0.249	0.328
Soft loam	0.499	0.656
Sand	1.000	1.312
Gravel	1 998	2.625
Pebbles	2.999	3.938
Broken stone, flint	4.003	5.570
Conglomerate, soft slate	4.988	6.564
Stratified rock	6.006	8.204
Hard rock	10.009	13.127

The following figures are selected from a diagram by W. A. Burr[1] showing the resistance of various soils to erosion by flowing water.

TABLE II. — MAXIMUM WATER VELOCITY IN CHANNELS.

Material.	Velocity in feet per second.
Pure sand	1.1
Sandy soil, 15 per cent clay	1.2
Sandy loam, 40 per cent clay	1.8
Loamy soil, 65 per cent clay	3.0
Clay loam, 85 per cent clay	4.8
Agricultural clay, 95 per cent clay	6.2
Clay	7.35

Masonry Flumes. Flumes are made either of masonry or of planking. The former resembles the trench, but has vertical walls. They may be made of brick, concrete or reinforced concrete.

Those made of concrete are the most common ones in use, and usually follow the contour of the ground. If concrete flumes have to cross valleys, either filling has to be made or else solid pier construction has to be used, in a way similar to the old Roman aqueducts, in which case reinforced concrete may be successfully employed. The wetted perimeter must be smooth, so as to allow a velocity of 7 to 8 feet per second. The bottom must have a slope of one-half to one foot in a thousand.

As an example of modern concrete flume construction, the one of the Kern River Power Plant is cited: The whole structure is carried on 15-inch I-beams set 8 feet 10 inches apart, supported by concrete piers. These longitudinal girders carry 9-inch steel I-beams laid transversely 4 feet center to center, and on them is erected a framework of structural steel for the sides and bottom of the flume. Two layers of expanded metal of 1.5 and 3-inch mesh are used in connection with this framework, and, being embedded in concrete, form the sides inclosing the frame. This concrete construction is also reinforced on the floor by twisted half-inch rods. The outside and inside of the flumes are plastered, making the thickness of the reinforced concrete sides and bottom 4 inches.

This type of flume or conduit, while it costs more than a wooden flume, has the advantage of being as permanent as tunnels themselves.

Wooden Flumes. Wooden flumes, which are used mostly in the West and Pacific Coast, are constructed of California fir, redwood and Oregon pine. They are best carried on trestlework or concrete piers, and are usually of the open type, and built on a slope of one-half to one foot in a thousand. The planking must be laid so that the pieces break joints. The wetted perimeter must be smooth to allow a velocity of 7 to 8 feet per second. They must be water tight, which may be done as given in an example below.[2]

[1] *Engineering News*, Feb. 8, 1894.

[2] Kern River Power Plant No. 1, by C. W. Whitney. *The Engineering Record*, Aug. 10, 1907.

With the installation of this plant, there are five wooden flumes, the longest being 1030 feet, the shortest being 50 feet. They are placed on concrete foundations, and are designed with a factor of safety sufficient to make their life from 30 to 40 years. The framework for supporting the flume box is of Oregon pine, being so designed and distributed that no part of the timber comes in contact with the earth, or is exposed to the drip should the flume at any point spring a leak. The flume box is built up of 3 by 12-inch redwood planks obtained from butt-ends of Sequoia Semper Virens, grown in swamp lands west of the coast range of northern California.

The grain of this lumber is perfectly clear, and its quality is such that its life should not be less than forty years. The edges of all planks were beveled so as to give a one-quarter inch opening on the inside of the joints, which is calked with

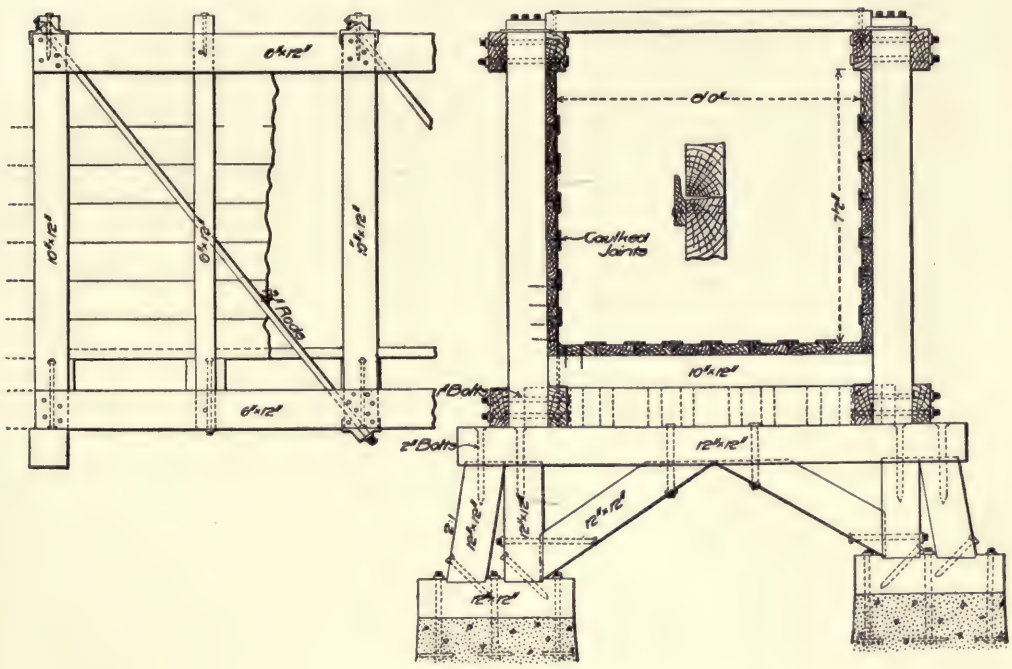


FIG. 2.—Detail of a Timber Flume, 32-foot Span.

ship-chandler's oakum. The bottom seams were covered with hot asphaltum and 1 by 6-inch redwood battens nailed down over them. On the sides of these flumes a specially designed batten is used. This batten is of 1 by 6-inch redwood, the upper half being cut away on a curve, permitting asphaltum to be poured between the batten and the side of the flume. At the corners of the flumes a quarter-round strip is nailed (Fig. 2).

The design of the flume above described has been thoroughly tested, and even if it should stand dry for months in the hottest weather, the designers stated that it may be again filled with water without having any perceptible leakage.

In some of the flumes where streams are crossed that are apt to carry considerable

water in winter, span flumes are constructed. One of these span flumes has a length of 32 feet, built with a 10 by 12-inch timber frame, resting on 12 by 12-inch beams. In connecting the wooden flume with the portal of a tunnel, a construction of a special nature was used, which offers two points of contact between the wood and the concrete, and a well between the two, from which the water may be pumped out, and any leaks repaired should these ever occur between the wood and the concrete.

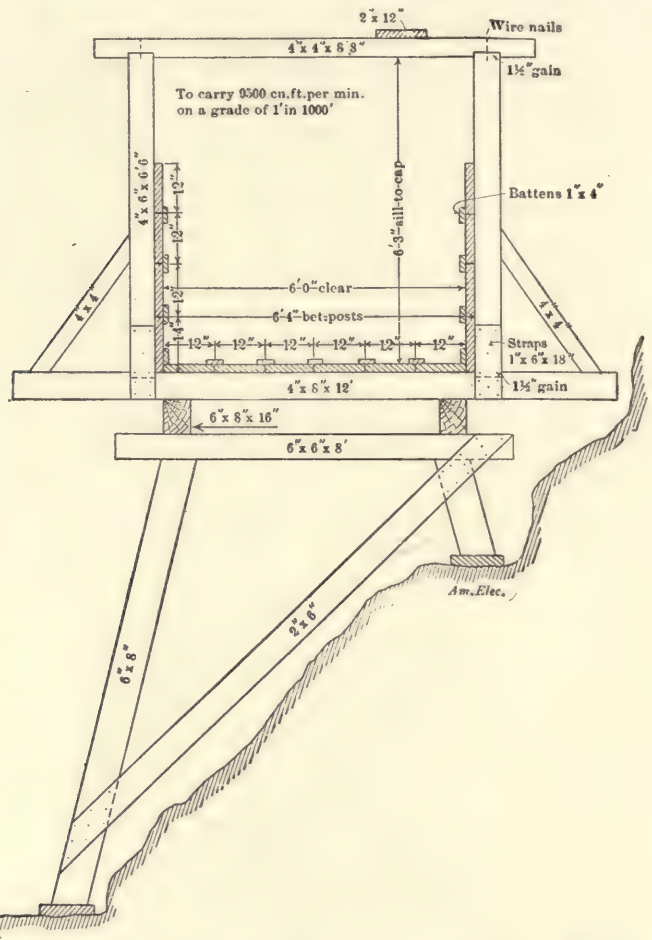


FIG. 3.—Timber Flume, on Mountain Slope. American River Electric Company.

Protection of Flumes. Frequently the flumes run on the sides of mountain slopes, and are endangered by loose boulders. Where flumes pass through such sections, they should be provided with some means of protection. One way of protecting the flumes is to build a retaining wall of sufficient height on the mountain side of the flume, to deflect the boulders across same. Another way is to cover the flume with concrete slabs, preferably reinforced with rods. Where loose boulders or land-slides are severe, the cover should have an arch form, and in any case, should be covered with at least two feet of earth to act as a cushion.

Tunnels. As stated, tunnels for hydraulic developments are classified as non-pressure and pressure tunnels. In the former case, the tunnel is only partly filled, and in the latter, it is completely filled and under pressure due to the head of the water. The cross section of the tunnel may be semi-egg-shaped, or rectangular with an arched roof. Where the tunnels run through loose soil, they must be lined, the thickness of which varies with the character of the soil and the pressure required to retain same. The lining may be made of brick, but in later years, concrete has been used exclusively. Where there is a possibility of a cave-in, they must preferably be reinforced with rods. The cross section should be uniform throughout, except near the collecting reservoir, so that it may serve as an additional storage. They are usually built with a slope of 1 to 2 feet in 1000, and have a velocity of 7 to 8 feet per second. Where the tunnel is several miles long, it is advisable to provide at every mile, access to same; this is usually done by vertical shafts. In cases where overflow side-tunnels are provided, these shafts may be eliminated.

Pressure Tunnels. In the last few years several plants have been installed with pressure tunnels, particularly in Europe. These tunnels are thoroughly and strongly lined, and as water tight as possible, because they are under pressure. Such tunnels are provided with a vertical shaft, the upper end of which is enlarged to serve as an air chamber and absorb fluctuations. One of the most notable examples making use of this system, is that of the Urfttalsperre installation, Germany. This plant is operating under a head varying from 230 to 360 feet. At the end of a 8850-foot tunnel is located the vertical or equilizer shaft. The top of this shaft, sunk through the mountain, is higher than the high-water level in the reservoir, so as to prevent, in case of sudden shut-down of the plant, a waste of water. It will be seen from this, that the equilizer shaft acts as a standpipe, similar to those installed on penstocks. These shafts are more economical than standpipes because they do not waste the water.

With exceptionally long pressure tunnels, it is advisable to install vent pipes along the line, to let out air which might collect, and prevent same from getting into the penstock.

Friction in Tunnels. In order to minimize friction in tunnels, the perimeter must be smooth, which is accomplished by a cement coating. In case of non-pressure tunnels, the coating should extend some 6 inches above the highest water level; while in pressure tunnels, the coating must extend over the whole of the interior surface. Where the tunnel is cut through hard rock, and a smooth surface is easily obtainable, the lining may be omitted and only a coating provided. This coating has to fill up small recesses in the rock, and to face the concrete lining. It is made of a mixture of one part sand and two of cement, and applied about a quarter of an inch thick.

Another way to reduce friction, is to have the course of the tunnel as straight as possible; short radius curves must be avoided. Where the side walls join the bottom, the junction must be a smooth curve.

Seepage in Tunnels. Where tunnels run through mountains and seepage water is encountered, provision must be made to take care of same. In high-pressure

tunnels, this trouble amounts to little or nothing, especially as these tunnels have to be constructed as water tight as possible. In non-pressure tunnels overflow devices may overcome the difficulty. These overflow devices are nothing more than overflow weirs, discharging into side tunnels taking the shortest cut to the mountain slope. Fig. 4 shows such a device, as installed in the Brusio Power Plant, Switzerland. The tunnel of this installation is 1756 feet long, built on a slope of 2 feet in 1000, and

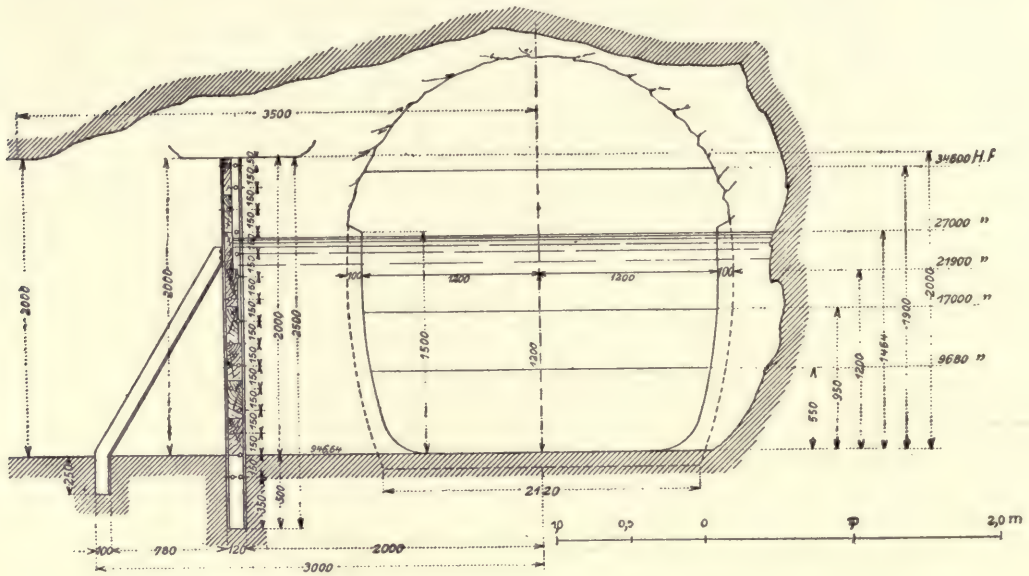


FIG. 4.—Overflow Device in Headrace Tunnel, Brusio Plant, Switzerland.

is provided with 11 overflow devices. It will be noticed that the main tunnel is only partly lined. In connection with same, the horsepower carrying capacity is indicated; of course this capacity applies only to this particular plant.

Construction of Tunnels. In the construction of long tunnels, which in some cases represent the greatest expenditure in hydroelectric engineering, temporary power plants are installed, particularly when plants are remote from power supply. Tunnels are usually begun at both ends, and in some cases at intermediate places, where shafts have been driven. Where intermediate junctions are to be made, and the character of soil is known, and varies from rock to soft earth, the junctions are best made at such places.

For cutting rock, pneumatic or electric drills are employed; two or more drills are mounted on a truck running on rails. Where the tunnel is driven through loam, special cutting machines which run on tracks may be employed. Cases sometimes arise, particularly in Switzerland, where the tunnels have to be cut under pressure; when such is the case, it is customary to heavily line the tunnel as fast as the work proceeds.

Siphon System. In some installations, in order to utilize the water of a mountain lake, the bottom of same has to be tapped, for which purpose sheet piling is driven.

A.E.&M.E
UNIV. OF CAL.

The tapping of a lake on the bottom is very troublesome, particularly when the soil is soft, and might cause failure in construction. Swiss engineers, in such a case, have adopted the siphoning system, which consists of sinking a vertical shaft, a safe distance from the shore of the lake, to which the headrace tunnel is connected. The water is siphoned from the lake into the shaft. One leg of the siphon is submerged in the shaft, and the other is carried on a trestle out into the lake, and extends down into same as far as possible, to take advantage of all the water available.

To the author's knowledge, the first siphon system installed was that of the Kubel plant, and the largest one, in connection with the Brusio plant, both in Switzerland.

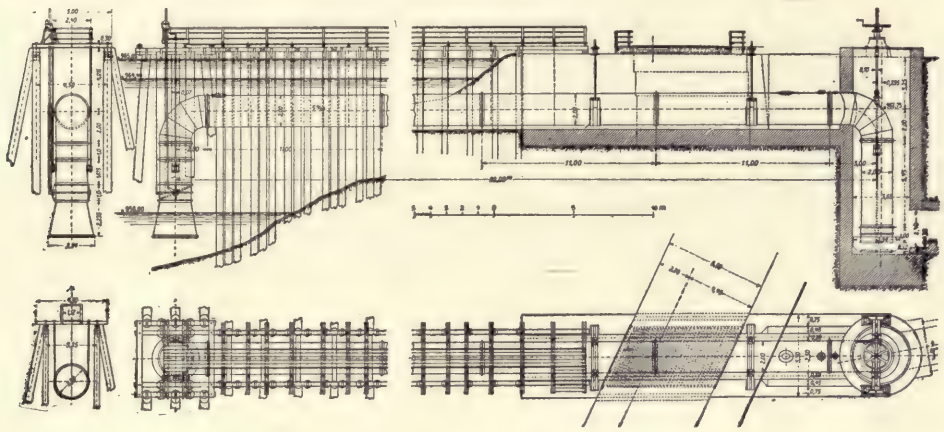


FIG. 5.—Siphon System at Lake Poschiavo.

An illustration of the latter is given in Fig. 5. The siphon tube is 6.5 feet in diameter and is made of $\frac{7}{16}$-inch material.

As it is submerged below the normal water-bed of the lake, it will start automatically. The horizontal part of the siphon is placed on a slope of 1 : 1000, and has, at the highest point, two pipe connections, one 3.5-inch for air pump and the other an 8-inch centrifugal pump connection. If for any reason the siphon should stop operating and the water level is low, either of the pumps may reëstablish the siphoning action.

Both ends of the siphon are provided with controlling valves. In addition to this, the suction leg has a one-inch mesh screen, which may be cleaned by breaking the siphon, and allowing the water to flow back, or the centrifugal pump may be applied to same.

RACKS AND GATES.

Racks. There are two different kinds of racks, one in which the bars are spaced far apart, and the other where they are near together. The former is known as rack, the latter as screen. The racks must be placed at the entrance to the forebay or the entrance to headrace, in order to keep the heavy floating material out. In small plants, these racks are made in sections, so that they may be easily removed and cleaned. In large plants, the racks are stationary and are made of heavy bars,

or sometimes light I-beams, all depending upon the force with which the floating material acts on the racks. No round bars or pipes should be used for this purpose, although the latter is sometimes used.

Racks, made of round material, will collect more foreign matter than flat or square bars, because the latter deflect better than the former. Further, it is more troublesome to clean racks with round bars than with flat ones, as the wedge action of floating material is greater with round than with flat bars. The space between the bars should not be less than 1.5 inches, and should never exceed 4 inches. This

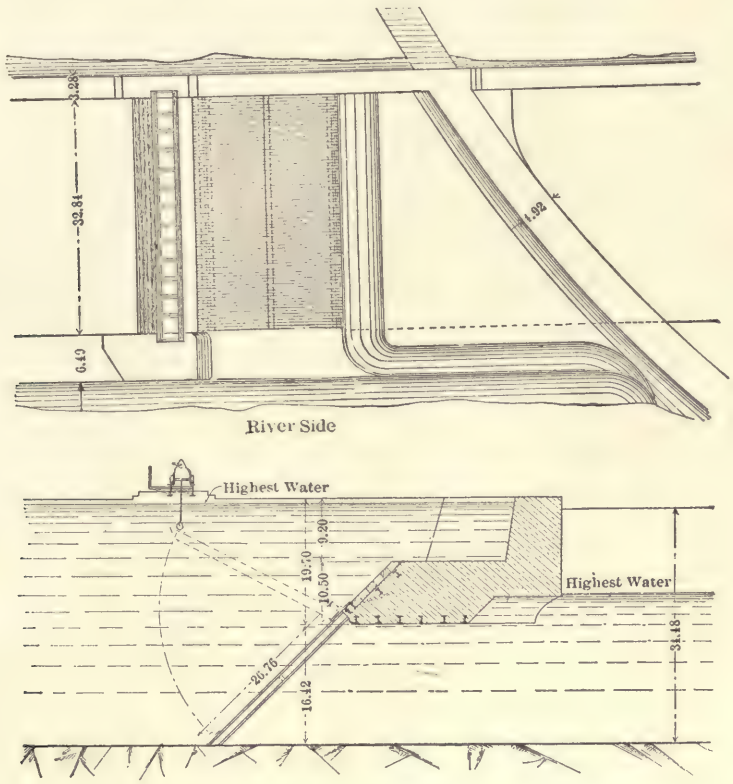


FIG. 6. — Screen House, Plant No. 2, Niagara Falls Power Company.

is particularly true when the racks are placed at the entrance of a long inclosed headrace, otherwise deflectors must be installed, to deflect material which passes the outside racks. If this is not done, there is a possibility of the headrace becoming clogged. Racks may be set vertically or at an angle, as long as the facility for cleaning is not sacrificed. Bars 3.5 by 0.5 inches, bolted together with separators, give a suitable construction for average conditions.

In plants where heavy material has to be deflected from the headrace, an arrangement similar to Figs. 7 and 8 might be adopted. It is a combined regulating device, rack and deflector, and has been installed in the headrace of the Hafslund Power Plant, Norway. As this is made of heavy I-beams, much clearance is allowed. Any material which passes the openings is prevented from entering the penstocks by two other racks, one rough and one fine. The former is in front of the forebay and provided with a sandtrap; the latter is directly in front of the penstocks.

As is seen in Fig. 8, there are two water levels, which are controlled by hoisting or lowering the I-beam rack. Even if the gate is open, the elevations will differ, owing to the deflector extending some 19 feet into the water. In certain seasons of the year, the rack is lowered so that anchor ice will either be broken up on the rack, or forced upward and deflected by the wall. Because the width of the headrace is 32.8 feet, it is necessary to split the rack into sections, to facilitate handling. By



FIGS. 7 and 8.—Deflector and Rack in Headrace, Hafslund Plant, Norway.

means of a windlass, which travels on a bridge, the different sections are hoisted and fastened to the latter. This serves a twofold purpose: first, reducing the weight to be lifted; second, the regulation of the water is better accomplished.

Screens. Screens are frequently made of 2 by $\frac{3}{8}$-inch bars. They are spaced from $\frac{5}{8}$ to $\frac{1}{2}$ inch apart. These screens, in almost all cases, are made in sections, with the exception of those at small-sized plants; even then, two screens are provided, so that when one is being cleaned the other is lowered. Such is seen in Figs. 3 and 4, which gives the general arrangement as well as construction. It will be noticed that there are two screens hoisted and lowered by a windlass. There is a walkway supported on brackets in front of the upper screen, so that the attendants may have free access for cleaning. The lower end of the bars of the rear screen are bent, so that when the screen is hoisted, the floating material goes with it.

It is advisable to place screens on an angle from 45 to 60 degrees; this not only brings submerged floating material to the surface, but adds greatly to the passage area of the screen, and reduces the velocity of water. Such screens are arranged in one row, so as to cover a number of penstock inlets; they are divided into sections, horizontally and vertically, and slide in vertical guides made of cast iron or rolled steel channels. When they are divided into vertical sections, they overlap each other

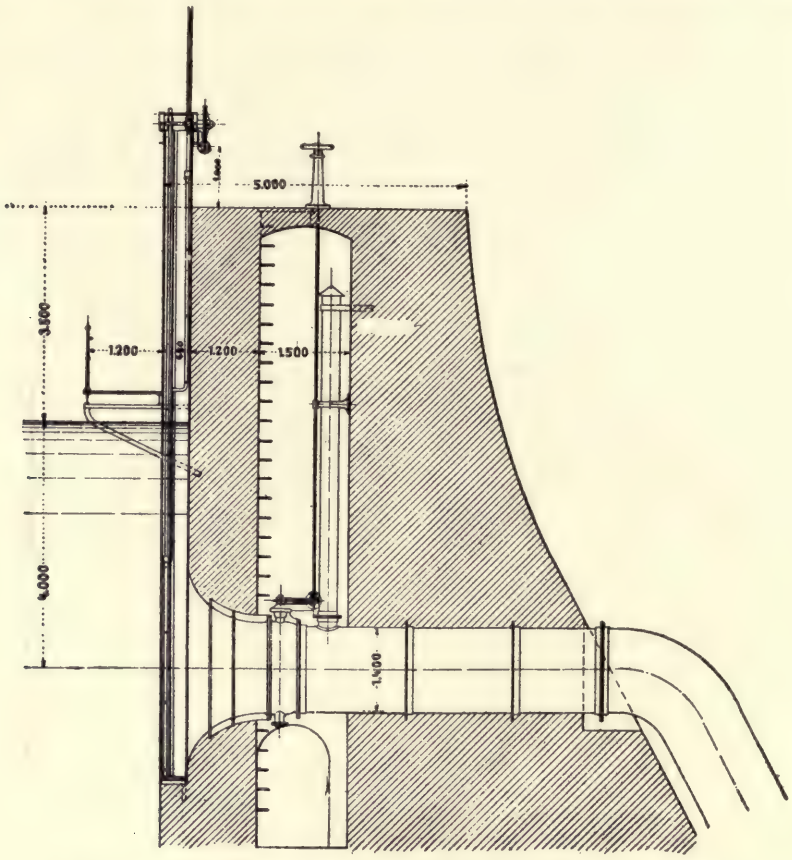


FIG. 9.—Arrangement of Screen and Vent of Penstock Inlet.

for several inches; they are arranged so that one or more sections may be hoisted independently of the others. By extending the abutments, the partition walls of the turbine chambers provide a very suitable support; otherwise they will have to be braced from the rear with structural steel; this of course depends on the size of the screen. Theory shows, that when the bars of the screen occupy one-quarter of the area of the water inlet to the turbine chamber, the drop in head due to resistance is from 2.5 to 3.5 per cent.[1]

Wooden Sluice Gates. For controlling the water supply in the headrace, usually vertical moving sluice gates are employed. The small sizes up to 100 square feet

[1] Gelpke, Turbinen und Turbinenanlagen, p. 142.

are made of wood, while the larger ones are made of structural steel. If conditions favor the use of large wooden sluice gates, they must be cut up into sections, otherwise they will be too bulky. The sections may be split up either vertically or hori-

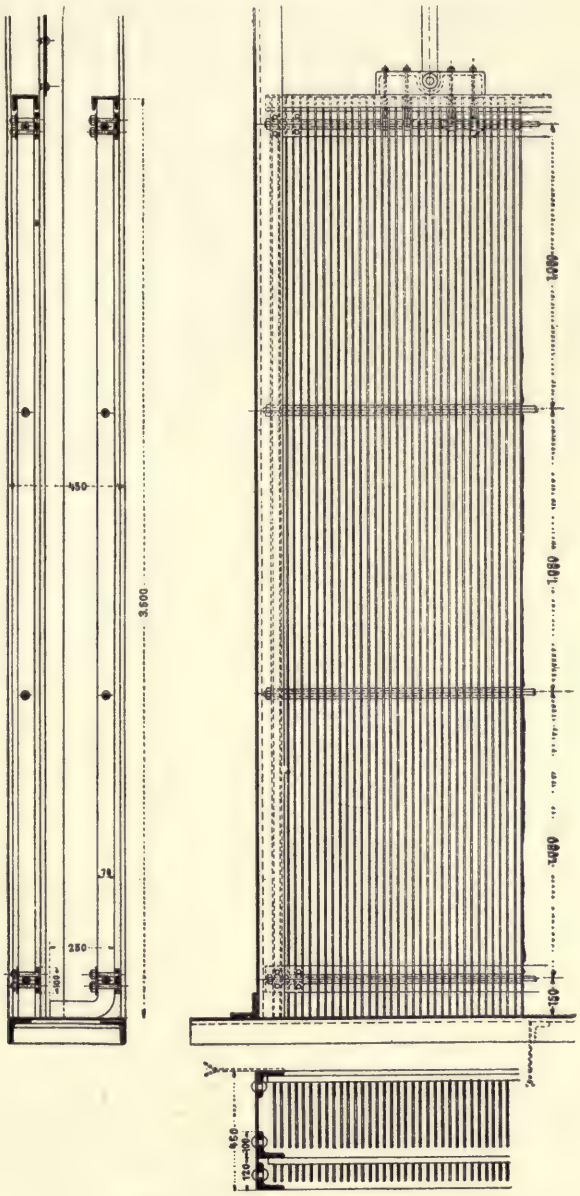


FIG. 10.—Detail of Screen.

zontally. In the former case, more guides are necessary, and as a single sluice gate extends through the entire depth of the water, the water flows underneath the gate. In the latter case, fewer guides are necessary, and the waste may flow through the bottom, middle or upper sluice gate. Besides this, the individual stages of such

types do not have to withstand the total head. Furthermore, this type of sluice gate is advantageously used in connection with sandtraps and overflows, particularly for ice. They may also be used as an adjustable weir, but in such cases they are usually made of structural steel.

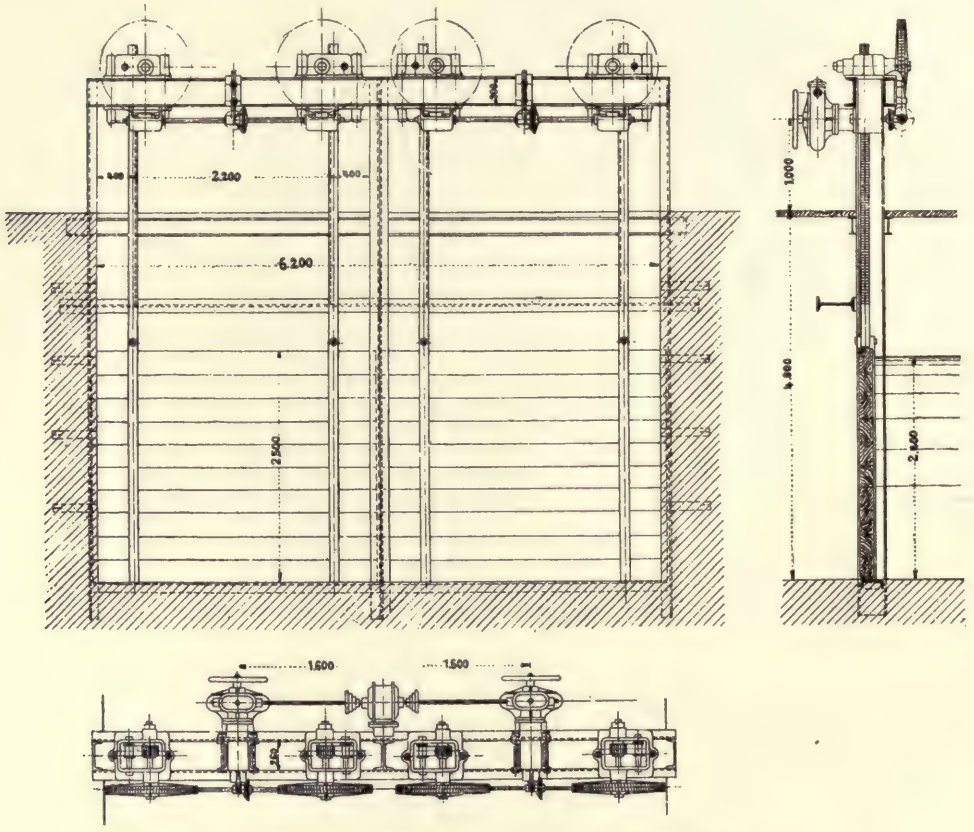


FIG. 11.—Wooden Sluice Gate. Hand and Motor Operated.

For calculating stresses in wooden sluice gates, the table on the following page is submitted.

It is compiled from a large number of tests; the maximum and minimum values are given. All of the test specimens had a sectional area of 1.575 by 1.575 square inches. The transverse specimens were 39.37 inches between supports, and the compressive-test specimens were 12.60 inches long. The modulus of rupture is calculated from the formula $R = \frac{3}{2} \frac{Pl}{bd^2}$.

P = load in pounds at the middle.

l = length in inches.

b = breadth in inches.

d = depth in inches.

TABLE I. — PROPERTIES OF TIMBER.

Description.	Weight per cubic foot in pounds.	Weight per foot B.M. in pounds, average.	Tensile strength per square inch, in pounds.	Crushing strength per square inch, in pounds.	Relative strength for cross breaking white pine = 100.	Shearing strength with the grain, pounds per sq. in.	Pressure in pounds per square inch to indent 0.05″.
Ash	43–55.8	4.1	11,000–17,207	4400–9363	130–180	458–700	1800–1850
Beech	43–53.4	3.9	11,500–18,000	5800–9363	100–144	.....	.....
Cedar	50–56.8	4.5	10,300–11,400	5600–6000	55–63	.....	.....
Cherry	.....	.....	.....	.....	130	.....	.....
Chestnut	33	2.75	10,500	5350–5600	96–123	.....	.....
Elm	34–36.7	2.9	13,400–13,489	6831–10,331	96	.....	.....
Hemlock	.....	.....	8700	5700	888–95	.....	.....
Locust	44	3.7	20,500–24,800	9113–11,700	132–227	.....	.....
Maple	49	4.1	10,500–10,584	8150	122–220	367–647	1700–1900
Oak, white	45–45.5	4.1	10,253–19,500	4684–9509	130–177	752–966	2300–3550
Oak, live	70	5.8	.....	6850	155–189	.....	.....
Pine, white	30	2.5	10,000–12,000	5000–5650	100	225–423	875–1160
Pine, yellow	28.8–33	2.6	12,600–19,200	5400–9500	98–170	296–415	1900
Spruce	.....	.....	10,000–19,500	5050–7850	86–110	253–374	875–1025

TABLE II. — TESTS OF AMERICAN WOODS.

Name of Wood.	Transverse tests, modulus of rupture.		Compression parallel to grain, pounds per square inch.	
	Max.	Min.	Max.	Min.
Yellow poplar, white wood	6,550	11,756	4,150	5,790
White wood, basswood	6,720	11,530	3,810	6,480
Red maple	8,610	13,450	6,010	7,500
Locust	12,200	21,730	8,330	11,940
Wild cherry	8,310	16,800	5,830	9,120
White ash	5,950	15,800	4,520	8,830
Slippery elm	10,220	13,952	6,980	8,790
White elm	8,250	15,070	4,960	8,040
Shellbark hickory	14,870	20,710	7,650	10,280
White oak	7,010	18,360	5,810	9,070
Red oak	9,760	18,370	4,960	8,970
Black oak	7,900	18,420	4,540	8,550
Chestnut	5,950	12,870	3,680	6,650
Beech	13,850	18,840	5,770	7,840
White cedar	6,310	9,530	2,660	5,810
Red cedar	5,640	15,100	4,400	7,040
White pine	5,610	11,530	3,750	5,600
Spruce pine	3,780	10,980	2,580	4,680
Long-leaved pine, southern pine	9,220	21,060	4,010	10,600
White spruce	9,900	11,650	4,150	5,300
Hemlock	7,590	14,680	4,500	7,420
Red fir, yellow fir	8,220	17,920	4,880	9,800
Tamarack	10,080	16,770	6,810	10,700

In connection with wooden sluice gates, particularly with less expensive or temporary installations, wooden guides are sometimes used. Tables I and II, giving the properties of timber and tests of woods, may be used in connection with same.

Wooden sluice gates, as they are usually of small size, may be operated by hand. Where a series of small gates are opened simultaneously, they may be operated by a single motor. Such a device is seen in Fig. 11.[1] It will be noticed that two wooden sluice gates, side by side, may be operated separately, by hand or by a motor; when desired, both gates may be operated simultaneously by a motor; friction clutches are located on both sides of the latter.

Iron Sluice Gates. Large head gates are usually made of structural steel, and on account of their heavy weight, are counterweighted. Provision must be made, so

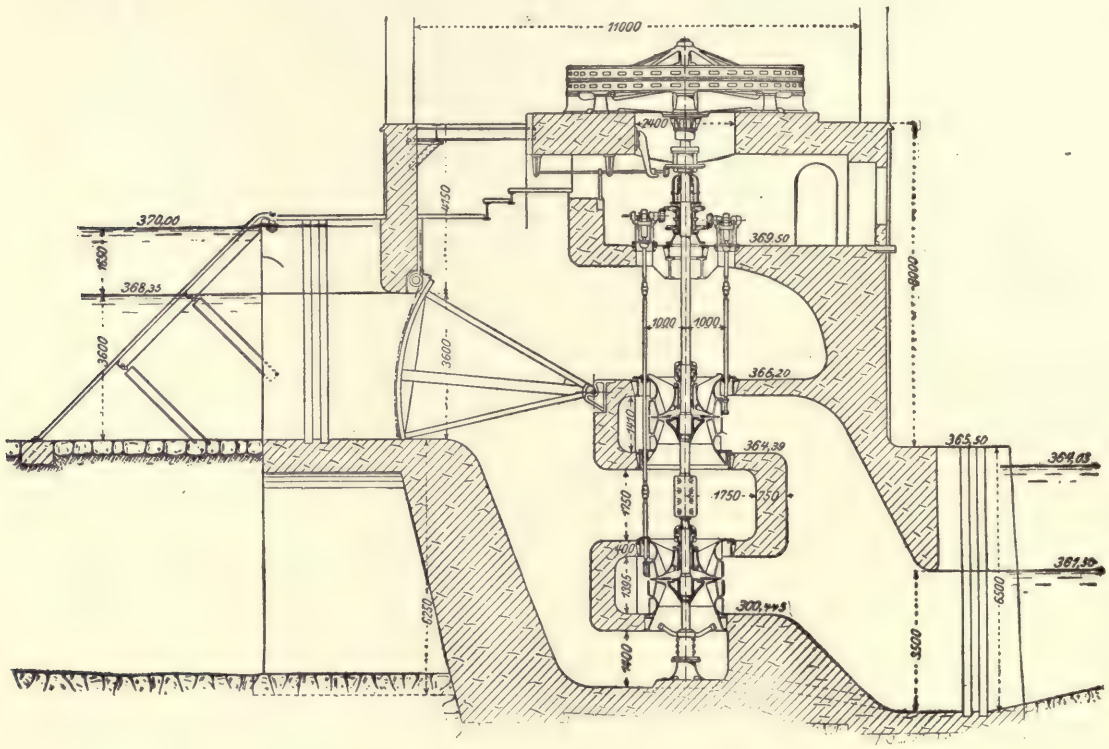


FIG. 12.—Application of Drum Gate, Chèvres Plant, France.

that they may be operated by hand, in addition to the regular motor operation of same. Low head plants usually employ several large-sized gates; they must be located side by side, and interconnected by an operating bridge. Where the turbine is placed in an open chamber, the water to the chamber is controlled by a separate gate. The type of gate varies greatly with the setting of the turbine. This may be done by a vertically operated sluice, drum or cylindrical gate. Sluice gates are the most common, and are frequently made of structural steel, provided with an auxiliary gate to facilitate operation; large gates usually are operated by a motor or hoist.

[1] Gelpke, Turbinen und Turbinenanlagen.

Where quick action is necessary, they are operated by air or hydraulic pressure. A gate of the latter type has been installed in the Beznau plant, Switzerland. They are 21.6 feet wide and 10.5 feet high, and provided with rollers, as they have to withstand a pressure of 18.7 tons. The lifting or lowering of these gates is accomplished by oil pressure, supplied by the same pumps furnishing oil to the step-bearings. As the sluice gates are in the open air, the cylinders are jacketed to protect them from frost. To protect the steel piston rod from rust, it is fitted with a brass sleeve.

Drum gates are made to swing either vertically or horizontally. A type of the latter has been installed in a plant at Rheinfelden, which has been in operation for many years. To the writer's knowledge, it has never been duplicated. A more

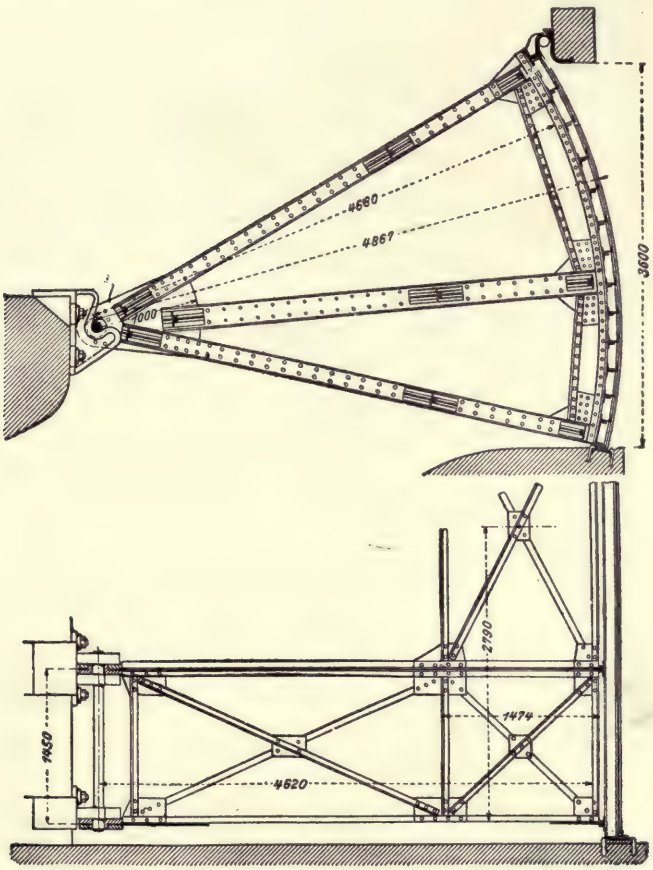


FIG. 13.—Detail of Drum Gate.

favored one is the vertical swinging type. They have been installed at Chèvres, France, and in many other plants. As the water presses against the drum (the gate being located in the turbine chamber; see Fig. 12), care must be taken to keep it tight, because the water is pressing it away from the seat. This may be accomplished by a rope or steel cable on top of the gate as seen in Fig. 13, and on the bottom by wooden

blocks. For operating the gate, a chain is fastened on the bottom of the drum and guided by sheaves. It may be raised by a separate hoist, or by the overhead crane in the generating room.

The application of a cylindrical gate is seen in Fig. 14. The whole gate consists of a cylinder with vertical slots, which are covered and uncovered, by moving a disk up and down by means of a windlass.

COLLECTING BASIN.

Scheme. The junction between the headrace and the penstock must be made by a collecting basin, provided it is not a pressure tunnel. This collecting basin should be large enough to overcome slight fluctuations. To increase the capacity of such

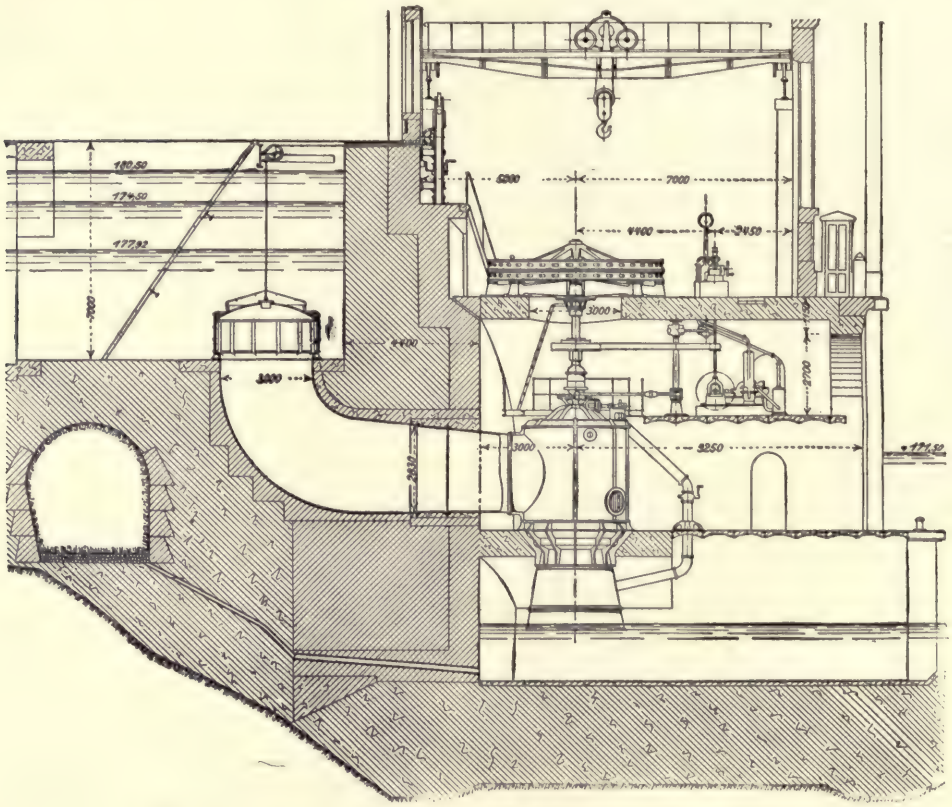


FIG. 14.—Application of Cylinder Gate, Lyon Plant, France.

a basin, the area of the headrace near the basin may be enlarged for a certain length. This may be well adopted if the headrace is a tunnel. Under ordinary conditions such a collecting basin is large enough when the velocity is only one foot per second. This velocity is sufficient to allow all heavy foreign material to settle, thus preventing it from entering the penstock. In most cases, the entrance to the penstock must

be protected with a fine screen, to prevent foreign material from entering the same. The screens are preferably placed on the skew, so that the water will push the foreign material to the gate of the sandtrap.

Sandtraps. A sandtrap is nothing more than a recess in the bottom of the collecting basin or headrace. The approach to the sandtrap must be gradual, so as to decrease the velocity of the water, and facilitate the settling of sand and gravel. At the deepest point, the trap is about two or three feet deep. The sandtrap must run on a skew, so that the foreign material will roll to the gate at the end. In many instances, there is no gate, only an opening, and the sand and gravel discharge all the time into the spillway.

Spillways. The collecting basin must be provided with a spillway, so that in case the water to the penstock is cut off, and the water in the headrace is not cut off, no damage is done to the collecting basin or penstock run. The spillway is usually nothing more than a partition wall in the collecting basin with a lower elevation, so that the surface water can overflow. The spillway must be provided with a sluice gate, so that the collecting basin and headrace may be emptied through same. To provide for protection against floating material, particularly ice, a sluice gate to be lowered is installed, contrary to the one which is raised. These two gates may be combined into one, as will be seen under Sluice Gates.

The discharge of the spillway is best done in cascades when the collecting basin is on a steep mountain slope, and discharged either into a river, or into the tailrace of the plant. The cascades break the fall of the water.

Attention is here called to the spillway of the Ontario Power Company, Niagara Falls. The water is forced over an adjustable weir and discharged into a vertical, helical shaft, which opens into the gorge below the falls. The helical course was chosen to prevent ice formation.

Gate Valves. All penstocks must be provided with cut-off valves at the collecting basin. They are usually of the gate valve type; in very rare instances butterfly valves have been used. The gate valves, also classed as sluice gates, are usually of simple form; the head presses the disk against the seat and keeps it tight. They are usually made of cast iron, and have babbit or bronze seats so as to keep them from rusting. When large valves are used, by-pass provision should be made, so as to properly fill the penstocks before the main valve is opened. The valves may be either hand or motor operated; they are sometimes of the remote control type, so that they can be operated from the power house.

To protect the operating mechanism of the gate valves, and other devices connected to the inlet of the penstock, a housing should be provided. In medium head plants, screens and gates may be of such size that they are difficult to handle by hand, in which case a hand-operated traveling crane must be used.

BIBLIOGRAPHY.

HYDRAULICS AND HYDRAULIC MOTORS. P. J. Weisbach. Translated by A. Jay Dubois. 1891. John Wiley & Sons. New York.

A TREATISE ON HYDRAULICS. Henry T. Bovey. 1901. John Wiley & Sons. New York.

TREATISE ON HYDRAULICS. Mansfield Merriman. 1903. John Wiley & Sons. New York.

HYDRAULICS. L. M. Hoskins. 1907. Henry Holt & Co. New York.

RIVER DISCHARGE. J. C. Hoyt and N. C. Grover. 1907. John Wiley & Sons. New York.

ICE TROUBLES IN HYDRAULIC POWER WORKS AND METHODS OF OVERCOMING THEM. John Murphy, Consulting Engineer. May 1, 1908.

THE FLOW OF WATER OVER DAMS AND SPILLWAYS. *Engineering Record*, June 2, 1900.

FLOW OF WATER OVER ROUNDED CREST. N. Werenskiold. *Engineering News*, Jan. 31, 1895.

THE FLOW OF WATER OVER DAMS. Geo. M. Rafter. *Proc. A. S. C. E.*, March, 1900.

EXPERIMENTS ON THE MEASUREMENT OF WATER OVER WEIRS. A. E. Victor Dery. *Proc. I. C. E.*, vol. 114, p. 333. 1893.

EXPERIMENTS ON THE FLOW OF WATER THROUGH LARGE GATES AND OVER A WIDE CREST. Chas. E. Kaberstroh. *Journal Association Engineering Societies*, January, 1890.

THE ESTIMATION OF DAMAGES TO POWER PLANTS FROM BACK WATER. *Engineering Record*, April 26, 1902.

INSTRUCTIONS FOR INSTALLING WEIRS, MEASURING FLUMES AND WATER REGISTERS. Johnson. *Engineering News*, Aug. 29, 1901.

NEW FORMULA FOR CALCULATING THE FLOW OF WATER IN PIPES AND CHANNELS. W. E. Foss. *Journal Association Engineering Societies*, vol. 13, p. 295. 1894.

MEASUREMENT AND DIVISION OF WATER. L. G. Carpenter. Bulletin 27, Colorado Agricultural Experiment Station, Fort Collins, Colorado. 1894.

DISCHARGE MEASUREMENTS OF STREAMS. F. H. Newell. *Proceedings Engineering Club*, Philadelphia, vol. 12, No. 2, p. 125. 1895.

COEFFICIENTS IN HYDRAULIC FORMULAS. W. J. Keating. *Journal Western Society Engineering*, vol. 1, p. 190. 1896.

EXPERIMENTAL DATA FOR FLOW OVER BROAD CREST DAM. F. T. Johnson and E. L. Cooley. *Journal Western Society Engineering*, vol. 1, p. 30. 1896.

STEAM GAUGINGS. Clarence T. Johnson. *Proceedings Purdue Society Civil Engineers*. 1897.

METHODS OF STEAM MEASUREMENT. Water Supply and Irrigation Paper, No. 56. 1901.

ACCURACY OF STEAM MEASUREMENT. E. C. Murphy. Water Supply and Irrigation Paper, No. 64. 1901.

THE LAWS OF RIVER FLOW. C. H. Tutton. *Journal Association Engineering Societies*, January, 1902.

METHODS OF MEASURING THE FLOW OF STREAMS. John C. Hoyt. *Engineering News*, Jan. 14, 1904.

A METHOD OF COMPUTING FLOOD DISCHARGE AND CROSS SECTION AREA OF STREAMS. E. C. Murphy. *Engineering News*, April 6, 1905.

CHAPTER IV.

PENSTOCKS.

STEEL PENSTOCKS.

Penstock Run. Penstocks must be laid in the shortest course to the power house, and in such a way as to avoid sharp turns. This may be done by running the penstocks through tunnels or trenches, or crossing valleys on trestles or piers. Conforming to modern practice, instead of one large penstock, several small ones are installed. They should be arranged side by side, and the bed selected for same should be as even as possible. If the natural ground cannot carry the penstocks, it must be reinforced to avoid any possibility of a semi-landslide, which in some cases have put plants out of commission.

Where a number of such penstocks are installed, it is well to build as part of the penstock bed, a permanent cable road, by which means sections of the penstocks are hoisted to place, as well as to facilitate the building of the penstock run; later on, the cableway is used for inspection and repair purposes.

Where multiple penstocks are laid, they must be interconnected, preferably at the power house, and properly equipped with valves, so that in case of emergency, the water of one penstock may feed other turbines.

Size of Penstocks. The size of the penstocks depends upon the amount of water to be carried and head available. Other conditions remaining the same, the velocity of water in a penstock under a high head must be greater than under a low head. However, plants have been installed, where the velocity in the penstocks under low and high heads is practically the same. For instance, with the horizontal section of the 18-foot penstock of the Ontario Power Company, Niagara Falls, under a head of about 20 feet, the velocity is 15 feet per second; the velocity in the 30-inch penstock of the Necaxa plant, under a head of 1300 feet, is 15 feet under normal full load, while under extremely high load, it is 18 feet per second.

As stated, the smaller the penstocks, the higher the velocity; in some plants with penstocks 1 to 2 feet in diameter, the water has a velocity of 20 to 30 feet per second. In most high head plants running under a head of 1000 feet and higher, and penstocks 2 to 3 feet in diameter, the velocity chosen is between 10 to 16 feet per second. The velocity of the water in the penstock depends greatly on the velocity in the turbine gates, or, in other words, the speed for which the water wheel has been designed. Therefore, the lower sections or branches must be designed to suit conditions. The main penstock must not have any sudden enlargements of diameter. The use of a drum at the end of a penstock, from which branches run to several turbines, must be avoided, because of the sudden change of speed in the water.

TABLE I.—AREA OF CIRCLES.

1	.79	18	254.47	35	962.11	52	2123.72	69	3739.29	86	5808.82
½	1.77	½	268.80	½	989.80	½	2164.76	½	3793.68	½	5876.56
2	3.14	19	283.53	36	1017.87	53	2206.19	70	3848.46	87	5944.69
½	4.90	½	298.65	½	1046.34	½	2248.01	½	3903.63	½	6013.22
3	7.06	20	314.16	37	1175.21	54	2290.23	71	3958.20	88	6082.14
½	9.62	½	330.06	½	1104.46	½	2332.83	½	4015.16	½	6151.45
4	12.56	21	346.36	38	1134.11	55	2375.83	72	4071.51	89	6221 15
½	15.90	½	363.05	½	1164.16	½	2419.23	½	4128.26	½	6291.25
5	19.63	22	380.13	39	1194.59	56	2463.01	73	4185.40	90	6361.74
½	23.75	½	397.61	½	1225.42	½	2507.19	½	4242.93	½	6432.62
6	28.27	23	415.48	40	1256.64	57	2551.76	74	4300.85	91	6503.90
½	33.18	½	433.74	½	1288.25	½	2596.73	½	4359.17	½	6575.56
7	38.48	24	452.39	41	1320.25	58	2642.09	75	4417.87	92	6647.65
½	44.17	½	471.44	½	1352.65	½	2687.84	½	4476.98	½	6720.08
8	50.26	25	490.88	42	1385.45	59	2733.98	76	4536.47	93	6792.92
½	56.74	½	510.71	½	1418.63	½	2780.51	½	4596.36	½	6866.16
9	63.61	26	530.93	43	1452.20	60	2827.44	77	4656.64	94	6939.79
½	70.88	½	551.55	½	1486.17	½	2874.76	½	4117.31	½	7013.82
10	78.54	27	572.56	44	1520.53	61	2922.47	78	4778.37	95	7088.23
½	86.59	½	593.95	½	1555.29	½	2970.58	½	4839.83	½	7163.04
11	95.03	28	615.75	45	1590.43	62	3019.08	79	4901.68	96	7238.25
½	103.87	½	637.94	½	1625.97	½	3067.97	½	4963.92	½	7313.84
12	113.10	29	660.52	46	1661.91	63	3117.25	80	5026.56	97	7389.83
½	122.72	½	683.49	½	1698.23	½	3166.93	½	5089.59	½	7466.21
13	132.73	30	706.86	47	1734.95	64	3217.00	81	5153.01	98	7542.98
½	143.13	½	730.62	½	1772.06	½	3267.46	½	5216.82	½	7620.15
14	153.94	31	754.76	48	1809.56	65	3318.31	82	5281.03	99	7697.71
½	165.13	½	779.31	½	1847.46	½	3369.56	½	5345.63	½	7775.66
15	176.72	32	804.25	49	1885.75	66	3421.20	83	5410.62	100	7854.00
½	188.69	½	829.57	½	1924.43	½	3473.24	½	5476.01	½	7932.74
16	201.06	33	855.30	50	1963.50	67	3525.66	84	5541.78	.. ..	.....
½	213.83	½	881.41	½	2002.97	½	3578.48	½	5607.95	.....	.....
17	226.98	34	907.92	51	2042.83	68	3631.69	85	5674.51	.....	.....
½	240.53	½	934.82	½	2083.08	½	3685.29	½	5741.47	.....	.....

It is frequently desirable to know what number of one-sized pipes will be equal in capacity to another pipe, for a given delivery of water. At the same velocity of flow, two pipes deliver as the squares of their internal diameters, but the same head will not produce the same velocity in pipes of different sizes or lengths, the difference being usually stated to vary as the square root of the fifth power of the diameter.

The friction of water within itself is very slight, and therefore the main resistance to flow is the friction upon the sides of the conduit. This extends to a limited distance, and is, of course, greater in proportion to the contents of a small pipe than of a large one. It may be approximated in a given pipe, by a constant multiplied by the diameter, or the ratio of flow found by dividing some power of the diameter

A.E.&M.E.
UNIV. OF CAL.

by the diameter increased by a constant. Careful comparison of a large number of experiments, by different investigators, has developed the following, as a close approximation to the relative flow in pipes of different sizes under similar conditions:

$$W \propto \sqrt{\frac{d^6}{d + 3.6}}, \text{ or, } \frac{d^3}{\sqrt{d + 3.6}}$$

W being the weight of fluid delivered in a given time, and d being the internal diameter in inches.

Friction. The laws governing the theoretical flow of water in long penstocks are derived chiefly from the formula:

$$v = \sqrt{2gh}.$$

The losses due to friction depend upon the length and diameter of the pipes, also the conditions of the inside of same, whether rusty, full of silt, dents in the pipe, etc. In brief, the laws may be stated as follows:

1. For equal velocities, the friction loss is proportional to the length of penstock.
2. Friction increases very nearly as the square of the velocity.
3. For equal lengths of pipe, the friction decreases with the diameter.
4. The rougher the interior surface, the greater the friction.

Loss of Head. The loss of head is chiefly due to the friction of water in the penstock, and may be calculated according to Weisbach as follows:

$$h = \left(.0144 + \frac{.01716}{\sqrt{v}}\right) \frac{l}{d} \frac{v^2}{2g}.$$

h = loss of head.
l = length of penstock in feet.
d = diameter of penstock in feet.
v = velocity in feet per second.

Another formula deduced by Wm. Cox, is as follows:

$$F = \frac{L}{1000\,D}(4\,V^2 + 5\,V - 2).$$

F = friction head.
L = length of pipe in feet.
D = diameter of pipe in inches.
V = velocity in feet per second.

Table II has been abstracted from tables given by the Pelton Water Wheel Company. It gives the loss of head by friction for each 100 feet of penstock for different diameters under different discharges in cubic feet at velocities from 2 to 7 feet per second. The Cox formula gives practically the same result.

Table III gives the capacity and friction head for velocities, varying from 8 to 15 feet per second. It must be noticed that the discharge is in gallons per minute. One U. S. gallon = 0.133 cubic foot.

TABLE II.—LOSS OF HEAD BY FRICTION IN PENSTOCKS.

Inside diameter of pipe in inches.

	12		13		14		15		16		18	
Vel. in feet per sec.	Loss of head in feet.	Cubic feet per min.	Loss of head in feet.	Cubic feet per min.	Loss of head in feet.	Cubic feet per min.	Loss of head in feet.	Cubic feet per min.	Loss of head in feet.	Cubic feet per min.	Loss of head in feet.	Cubic feet per min.
2.0	.198	94	.183	110	.169	128	.158	147	.147	167	.132	212
3.0	.407	141	.375	166	.349	192	.325	221	.306	251	.271	318
4.0	.685	188	.632	221	.587	256	.548	294	.513	335	.456	424
5.0	1.03	235	.949	276	.881	321	.822	368	.770	419	.685	530
6.0	1.43	283	1.325	332	1.229	385	1.148	442	1.076	502	.957	636
7.0	1.91	330	1.75	387	1.630	449	1.520	515	1.430	586	1.270	742
	20		**22**		**24**		**26**		**28**		**30**	
2.0	.119	262	.108	316	.098	377	.091	442	.084	513	.079	589
3.0	.245	393	.222	475	.204	565	.188	663	.174	770	.163	883
4.0	.410	523	.373	633	.342	754	.315	885	.293	1026	.273	1178
5.0	.617	654	.561	792	.513	942	.474	1106	.440	1283	.411	1472
6.0	.861	785	.782	950	.717	1131	.662	1327	.615	1539	.574	1767
7.0	1.143	916	1.040	1109	.953	1319	.879	1548	.817	1796	.762	2061
	33		**36**		**39**		**42**		**45**		**48**	
2.0	.073	712	.066	848	.061	995	.057	1155	.053	1325	.050	1508
3.0	.148	1070	.135	1273	.125	1442	.117	1730	.109	1987	.102	2260
4.0	.248	1425	.228	1697	.210	1990	.195	2310	.182	2650	.171	3016
5.0	.374	1780	.342	2121	.316	2490	.294	2885	.273	3310	.256	3770
6.0	.520	2140	.479	2545	.441	2986	.408	3461	.382	3970	.358	4524
7.0	.693	2495	.636	2968	.586	3484	.545	4030	.509	4638	.476	5277

TABLE III. — CAPACITY IN GALLONS PER MINUTE DISCHARGED AT VELOCITIES IN FEET PER SECOND, FROM 8 TO 15; ALSO FRICTION HEAD IN FEET PER 100 FEET LENGTH OF PIPE.

Dia. Pipe.	1-inch.		2-inch.		3-inch.		4-inch.		5-inch.		6-inch.		Dia. Pipe.
Velocity.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Velocity.
8	19.58	24.5	78.32	12.2	176.24	8.16	314.12	6.12	489.68	4.90	705.64	4.08	8
8½	20.80	27.4	83.23	13.7	187.25	9.15	333.75	6.86	520.61	5.49	749.01	4.57	8½
9	22.03	30.5	88.11	15.2	198.27	10.1	352.26	7.64	550.89	6.11	793.72	5.09	9
9½	23.25	33.8	93.00	16.9	209.24	11.2	371.90	8.46	581.25	6.77	837.08	5.61	9½
10	24.48	37.3	97.90	18.6	220.30	12.4	391.40	9.33	612.10	7.46	881.80	6.21	10
10½	25.70	40.9	102.80	20.4	231.31	13.6	411.05	10.2	642.43	8.19	925.20	6.82	10½
11	26.92	44.7	107.69	22.3	242.33	14.9	430.54	11.1	673.31	8.95	969.88	7.45	11
11½	28.15	48.7	112.58	24.3	253.34	16.2	450.20	12.1	703.62	9.74	1013.3	8.11	11½
12	29.37	52.8	117.48	26.4	264.36	17.6	470.68	13.2	734.52	10.5	1057.9	8.80	12
13	31.82	61.5	127.27	30.7	286.39	20.5	509.82	15.3	795.73	12.3	1145.0	10.2	13
14	34.27	71.0	137.06	35.5	308.42	23.7	548.96	17.7	856.94	14.2	1233.1	11.8	14
15	36.72	81.0	146.85	40.5	330.45	2.70	587.10	20.3	918.15	16.2	1321.2	13.5	15

Dia Pipe.	7-inch.		8-inch.		10-inch.		12-inch.		15-inch.		18-inch.		Dia. Pipe.
Velocity.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Velocity.
8	959.44	3.49	1253.4	3.06	1958.4	2.45	2820.1	2.08	.....	.....	.....	.....	8
8½	1019.4	3.92	1331.5	3.43	2080.8	2.74	2996.3	2.33	4688.1	1.82	6741.9	1.52	8½
9	1079.4	4.36	1410.1	3.82	2203.2	3.05	3172.7	2.60	4957.7	2.04	7138.1	1.70	9
9½	1139.4	4.83	1488.0	4.23	2325.6	3.38	3348.9	2.88	5232.1	2.25	7534.8	1.88	9½
10	1199.3	5.33	1566.8	4.66	2448.0	3.73	3525.2	3.17	5508.4	2.50	7931.0	2.07	10
10½	1259.3	5.84	1645.8	5.22	2570.8	4.09	3701.4	3.48	5783.4	2.73	8328.8	2.27	10½
11	1319.2	6.39	1723.5	5.59	2692.8	4.47	3877.7	3.80	6058.2	2.98	8724.9	2.48	11
11½	1379.2	6 95	1801.5	6.08	2815.2	4.87	4053.8	4.14	6334.6	3.25	9121.7	2.70	11½
12	1439.2	7.54	1880.2	6 60	2937.6	5.28	4230.2	4.49	6609.9	3.52	9517.8	2.93	12
13	1559.1	8.79	2036 8	7.90	3182.4	6.15	4582.8	5.23	7160.6	4.10	10310.	3.42	13
14	1679.0	10.1	2193.5	8.87	3427.2	7.10	4935.4	6.03	7711.4	4.73	11104.	3.93	14
15	1799.0	11.6	2350.2	10.1	3672.0	8.10	5287.8	6.89	8262.1	5.40	11897.	4.50	15

Dia. Pipe	20-inch.		24-inch.		30-inch.		36-inch.		42-inch.		48-inch.		Dia. Pipe.
Velocity.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Capacity.	Friction.	Velocity.
8½	8323.6	1.37	11985.	1.14	18725.	.915	26967.	.760	36704.	.653	47942.	.571	8½
9	8812.	1.53	12690.	1.27	19827.	1.01	28554.	.847	38863.	.728	50762.	.636	9
9½	9302.6	1.69	13395.	1.40	20928.	1.12	30140.	.938	41022.	.806	53582.	.694	9½
10	9792.	1.87	14100.	1.55	22030.	1.24	31726.	1.03	43181.	.888	56403.	.778	10
10½	10281.	2.05	14805.	1.70	23131.	1.36	33313.	1.13	45340.	.975	59223.	.851	10½
11	10771.	2.24	15510.	1.86	24233.	1.49	34899.	1.16	47499.	1.06	62043.	.930	11
11½	11258.	2.43	16215.	2.03	25338.	1.62	36485.	1.35	49658.	1.16	64863.	1.00	11½
12	11750.	2.64	16920.	2.20	26436.	1.76	38072.	1.46	51817.	1.26	67683.	1.10	12
13	12729.	3.08	18330.	2.56	28639.	2.05	41244.	1.70	56135.	1.46	73324.	1.28	13
14	13708.	3.55	19740.	2.95	30842.	2.37	44417.	1.97	60453.	1.69	78964.	1.48	14
15	14688.	4.05	21150.	3.37	33045.	2.70	47590.	2.24	64771.	1.93	84604.	1.69	15

Strength. In calculating the thickness of the penstock shell, the following formula may be used:

$$t = \frac{pds}{T}.$$

t = thickness of shell in inches.
p = pressure in pounds per square inch.
d = internal diameter in inches.
T = tensile strength.
s = factor of safety.

Tensile strength of mild steel may be taken as 60,000 pounds per square inch. Wrought iron 50,000 pounds per square inch.

For calculating the circumferential pressure in a penstock, the following formula may be used:

$$i = \frac{pr}{t}.$$

i = intensity of strain.
p = pressure head.
r = radius of pipe.
t = thickness of shell.

For stresses in riveted pipes, the following formula may serve:

$$i = etk.$$

i = intensity of strain.
e = modulus of elasticity.
t = change of temperature.
k = coefficient of expansion.

In low head plants, where large-sized penstocks are used, the plates are made heavier, so that when the penstocks are emptied, they will retain their form. Another way to accomplish the same result is to reinforce the top section.

Construction. Steel penstocks are made either riveted or welded. The former is made up of sheet steel or iron plates, which are rolled in the shop or field. The latter is resorted to, only in the case of very large pipes, in order to save freight rates. Lap joints are made single, double or triple riveted according to the head used. Under high heads the number of rivets in the lower sections of the penstocks increase; this means additional friction or loss of head. To overcome these difficulties, many plants use welded pipes in such places; among the prominent ones on the American Continent is the Necaxa plant in Mexico. Of the penstocks installed at this plant, there are 6 thirty-inch penstocks, each having a length of 2460 feet. The lowest sections are subjected to a static head of 1200 to 1300 feet. They are seamless welded pipes, and have a thickness varying from 0.4 to 0.95 of an inch, and were shipped from Germany in 29.5-foot lengths.

A system of welding steel, particularly penstocks, pipes, etc., has been in use in Germany for a number of years. It is strange to note that American firms are very slow to adopt this system; because of this a large number of penstocks, amounting to many miles, are purchased abroad and shipped to the American Continent.

TABLE IV. — RIVETED HYDRAULIC PIPES.

Diameter of pipe in inches.	Thickness of material, U. S. standard gauge.	Equivalent thickness in inches.	Head in feet pipe will safely stand.	Weight per lineal foot in pounds.	Diameter of pipe in inches.	Thickness of material, U. S. standard gauge.	Equivalent thickness in inches.	Head in feet pipe will safely stand.	Weight per lineal foot in pounds.
3	18	.05	810	2.25	18	12	.109	295	25.25
4	18	.05	607	3.00	18	11	.125	337	29.00
4	16	.062	760	3.75	18	10	.14	378	32.50
5	18	.05	485	3.75	18	8	.171	460	40.00
5	16	.062	605	4.50	20	16	.062	151	16.00
5	14	.078	757	5.75	20	14	.078	189	19.75
6	18	.05	405	4.25	20	12	.109	265	27.50
6	16	.062	505	5.25	20	11	.125	304	31.50
6	14	.078	630	6.50	20	10	.14	340	35.00
7	18	.05	346	4.75	20	8	.171	415	45.50
7	16	.062	433	6.00	22	16	.062	138	17.75
7	14	.078	540	7.50	22	14	.078	172	22.00
8	16	.062	378	7.00	22	12	.109	240	30.50
8	14	.078	472	8.75	22	11	.125	276	34.50
8	12	.109	660	12.00	22	10	.14	309	39.00
9	16	.062	336	7.50	22	8	.171	376	50.00
9	14	.078	420	9.25	24	14	.078	158	23.75
9	12	.109	587	12.75	24	12	.109	220	32.00
10	16	.062	307	8.25	24	11	.125	253	37.50
10	14	.078	378	10.25	24	10	.14	283	42.00
10	12	.109	530	14.25	24	8	.171	346	50.00
10	11	.125	607	16.25	24	6	.20	405	59.00
10	10	.14	680	18.25	26	14	.078	145	25.50
11	16	.062	275	9.00	26	12	.109	203	35.50
11	14	.078	344	11.00	26	11	.125	233	39.50
11	12	.109	480	15.25	26	10	.14	261	44.25
11	11	.125	553	17.50	26	8	.171	319	54.00
11	10	.14	617	19.50	26	6	.20	373	64.00
12	16	.062	252	10.00	28	14	.078	135	27.25
12	14	.078	316	12.25	28	12	.109	188	38.00
12	12	.109	442	17.00	28	11	.125	216	42.25
12	11	.125	506	19.50	28	10	.14	242	47.50
12	10	.14	567	21.75	28	8	.171	295	58.00
13	16	.062	233	10.50	28	6	.20	346	69.00
13	14	.078	291	13.00	30	12	.109	176	39.50
13	12	.109	407	18.00	30	11	.125	202	45.00
13	11	.125	467	20.50	30	10	.14	226	50.50
13	10	.14	522	23.00	30	8	.171	276	61.75
14	16	.062	216	11.25	30	6	.20	323	73.00
14	14	.078	271	14.00	30	$\frac{1}{4}$	.25	404	90.00
14	12	.109	378	19.50	36	11	.125	168	54.00
14	11	.125	433	22.25	36	10	.14	189	60.50
14	10	.14	485	25.00	36	$\frac{3}{16}$	.187	252	81.00
15	16	.062	202	11.75	36	$\frac{1}{4}$	.25	337	109.00
15	14	.078	252	14.75	36	$\frac{5}{16}$	.312	420	135.00
15	12	.109	352	20.50	40	10	.14	170	67.50
15	11	.125	405	23.25	40	$\frac{3}{16}$	.187	226	90.00
15	10	.14	453	26.00	40	$\frac{1}{4}$	.25	303	120.00
16	16	.062	190	13.00	40	$\frac{5}{16}$	.312	378	150.00
16	14	.078	237	16.00	40	$\frac{3}{8}$	.375	455	180.00
16	12	.109	332	22.25	42	10	.14	162	71.00
16	11	.125	379	24.50	42	$\frac{3}{16}$	.187	216	94.50
16	10	.14	425	28.50	42	$\frac{1}{4}$	.25	289	126.00
18	16	.062	168	14.75	42	$\frac{5}{16}$	.312	360	158.00
18	14	.078	210	18.50	42	$\frac{3}{8}$	.375	435	190.00

This process is known as "autogenous welding." It embraces all methods of welding in which the parts are joined in a homogeneous manner, the joints being made by the intermingling contacts of the fibers of the material to be welded, so that the finished piece is one of uniform quality and properties throughout. The process is carried on by several methods, viz., the oxy-acetylene, the purely electrical, and the oxy-hydrogen method. The latter is the most extensively used, and has been discussed by the author in the technical press.[1]

By using welded penstocks, it will be readily observed that additional head is obtained because of the absence of rivets.

No fixed rules can be laid down for penstock construction, as it all depends upon the nature of the conditions under which the steel penstock is to be constructed. To give an example of a prominent steel penstock construction on the American Continent, that of the Kern River Power Plant[2] of California is cited. It has many notable features, and, contrary to the customary practice on mountain slopes, it is run through tunnels. The steel penstock serves as a lining to the rock-cut tunnel.

The penstock consists of a tunnel approximately 1700 feet long driven through the mountains on an incline and lined with steel, varying in thickness from $\frac{3}{16}$ to $1\frac{1}{2}$ inches. This tunnel begins at the bottom of the forebay, and is carried down at an angle of approximately 45 degrees, and, turning into the horizontal section, emerges at the lower end on a level with the floor of the power station. There are three vertical curves in the tunnel. The upper one forms an angle of 7 degrees, 260 feet from the forebay floor, and turns the pipe from a grade of 130.32 per cent to a grade of 101.35 per cent. The second curve 32.5 feet lower down has an angle of 5 degrees, and turns the pipe into a grade of 84.93 per cent on which it is carried 994.24 feet

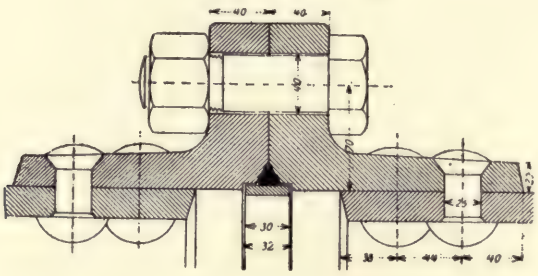


FIG. 1.—Type of Penstock Flange used in recent Swiss Practice.

to the last vertical curve. The latter has an angle of 40 degrees, and from its lower end the pipe is carried along horizontally to the power house, the total length of the main being 1697 feet.

The penstock is finished to give it an inside diameter of 7 feet 6 inches. At the top, a taper, 20 feet long and 10 feet in diameter at the forebay entrance, terminates in the

[1] Oxy-hydrogen Welding. *Electrical World*, May 9, 1908.

[2] Kern River Power Plant, by C. W. Whitney. *The Engineering Record*, Aug. 10, 1907.

regular $7\frac{1}{2}$ feet diameter of the completed tunnel tube. This diameter of $7\frac{1}{2}$ feet is maintained throughout the inclined tunnel, and on the horizontal beyond vertical curve No. 3, for a distance of 167.39 feet.

At this point, 1454.44 feet from the forebay, the penstock emerges from the solid rock and is carried to the portal, a distance of 243 feet, through a detrital deposit, lying between the mountain and the power-house site. Where the tunnel emerges from the solid rock, a 20-foot taper was installed, reducing the diameter of the main from $7\frac{1}{2}$ to $5\frac{1}{4}$ feet, at which diameter the pipe is carried to the branch piping at the power house.

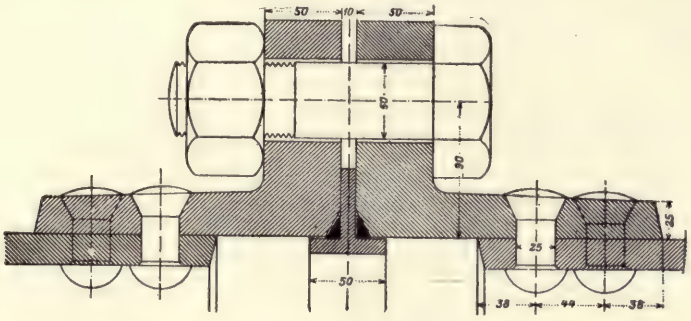


FIG. 2.—Type of Penstock Flange used in recent Swiss Practice.

The inclined part of the pressure main, and the portion of the horizontal section that is carried through solid rock, were finished by installing a steel lining built up of plates three-sixteenths inch thick for the incline, and three-eighths inch thick for the horizontal section, riveted together to form a cylindrical pipe, $7\frac{1}{2}$ feet in internal diameter. The tunnel itself was driven in approximately circular form and 9 feet in diameter. The steel pipe was centered in the tunnel, being installed in 10-foot sections, and the space between the outside of the steel lining and the bed rock was thoroughly filled with a mixture of 1 : 3 : 3 concrete. The work of installing this lining was begun at the lower end in the horizontal section, where the pipe is tapered down to a diameter of $5\frac{1}{4}$ feet. At this point, the 20-foot taper, already mentioned, was placed. It consisted of $1\frac{3}{8}$-inch steel plates riveted together with butt straps. The taper was placed back in the solid rock, and around it was constructed a heavy bulkhead of concrete, which was anchored into the bed rock by means of steel rods driven into the sides. From this point, the installation of the light steel lining with concrete back-fill, as already stated, progressed from the bottom to the top of the tunnel, terminating at the reinforced concrete taper that connects with the floor of the forebay.

The rock formation, through which the penstock tunnel was driven, is not of the best kind, being very much fractured and broken. It was necessary to timber the greater part of the shaft or incline when it was excavated, and these timbers had to be removed before the steel lining was installed. The timbers were removed ahead of the steelwork, the bed cleaned off, and the concrete tamped into place without difficulty. At a point about 120 feet below the top, the men in charge removed some

timbers without bracing the bents above. This precipitated a cave-in of the shaft, and several men lost their lives, one man being imprisoned for two weeks, after which time he was rescued in good condition. In retimbering the caved portion, octagon steel sets of 7-inch 15-pound I-beams were used, these sets being left in place when the concrete was filled in behind the steel lining.

The lower end of the pressure main, below the taper reducing the diameter to $5\frac{1}{4}$ feet, was made of $1\frac{3}{8}$-inch steel plates sufficiently heavy to withstand the static pressure without any external support. No concrete was placed around this pipe, and the tunnel was merely left in its original condition with the timber set to support the ground overhead.

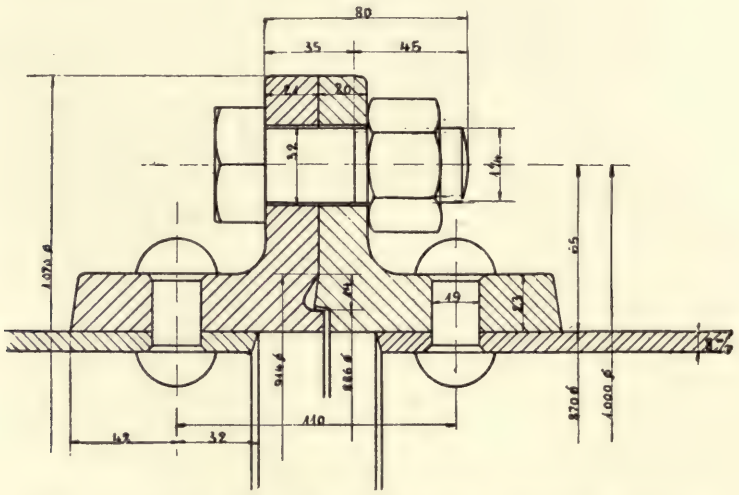


FIG. 3.—Flange used at the Brusio Plant (1300-foot. Head).

At a point 215 feet above the power house, a manhole was placed in the inclined tunnel for convenience on inspecting, and for use in case any repair work was necessary. The regular $\frac{3}{16}$-inch steel lining was replaced at this point by a section of $1\frac{1}{2}$-inch pipe 30 feet long.

The steel pipe was shipped to Camp No. 1 at the power house from San Francisco, in 5-foot lengths, 5 sections being nested together for shipment. The outside section was riveted complete on its two longitudinal seams, but the four inner sections were riveted on one seam only, so as to allow for the nesting. At the camp, the pipe was riveted into 10-foot lengths, and hoisted by means of an aerial tram to the forebay site at the upper end of the pressure tunnel. There the sections were secured to a dolly car, and lowered by means of a hoist to the point where they were to be riveted together. This car consisted of a truck at each end of the pipe sections, the latter being hung from two timbers that passed through the pipe, and rested on the axles of the truck.

All the piping in the pressure tunnels, which is constructed of steel plates of one-half-inch thickness and under, is made up with standard lap joints, double riveted

on the longitudinal seams and single riveted on round seams. All pipe on the work over one-half inch in thickness, is made up of butt strapped joints throughout, with triple riveting on each side of the longitudinal seams, and double riveting on each side of the round seams.

After the steel lining was completed, an inspection revealed the fact, that there were several places along the bottom of the pipe where voids had been formed in the concrete backing.

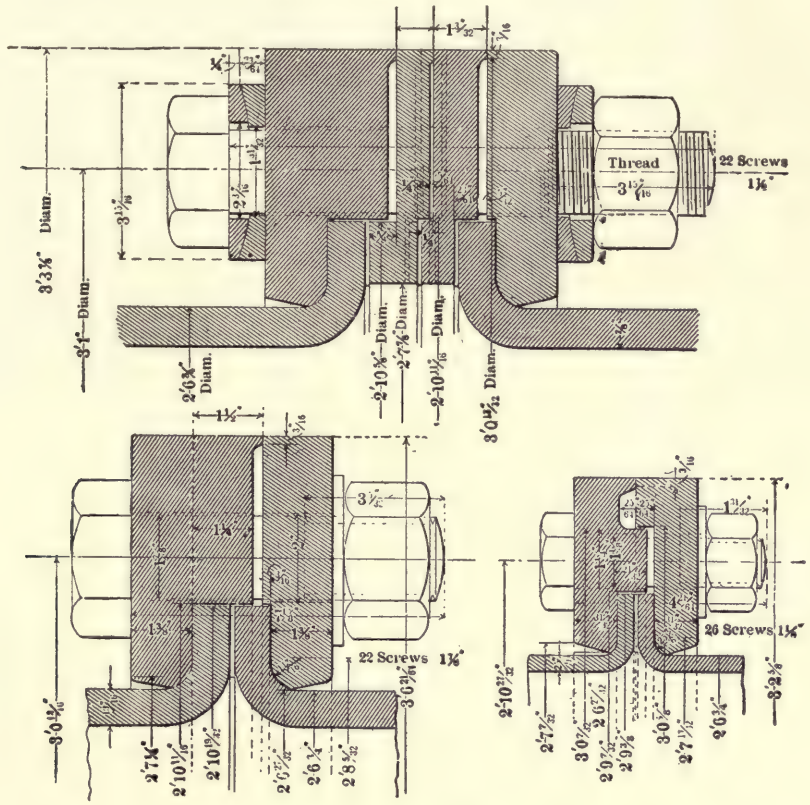


FIG. 4.—Type of Penstock Flanges for Necaxa Plant, Mexico.

These voids, which were revealed by tapping, were caused mainly by the difficulty experienced in tamping the concrete thoroughly around the steel lining. These steel sections were 10 feet in length, and in a few places where irregular rock excavation occurred at the bottom of a section, with but a 9-inch space at the top for handling the tamping bars, some voids were naturally formed because of the insufficient tamping.

Whenever these voids occurred, the pipe was tapped and liquid cement forced in until the hole was filled. The apparatus designed on the spot to accomplish this work was an ingenious one. A section of 3-inch steel tube 20 inches long was fitted at the bottom with a cap that would fit the hole drilled in the steel lining. Liquid

cement was poured into the void by means of this pipe, which had a capacity of about an ordinary pail. When no more cement would run in, there was fitted in the pipe, a screw with a plunger at the lower end and a crank at the outer end. By means of this device, the cement was forced into the void under pressure until it would hold no more. The pump was then removed and the hole in the lining was stopped up by an ordinary flush pipe plug. There were 116 of these voids tapped and filled through the lining; only three of them were of any size. A number of the voids required only a pint of the liquid cement, the quantity used varying up to the largest, for which ten buckets of the slush were necessary. The slush used was a liquid mixture of Portland cement and sand. The work was carried on from a dolly car fitted with beveled wheels, lowered down from the top by a steel cable. About 15 days were necessary to complete this special work. After all the voids were filled, the entire pipe was painted with asphaltum, the same dolly car being used for the purpose.

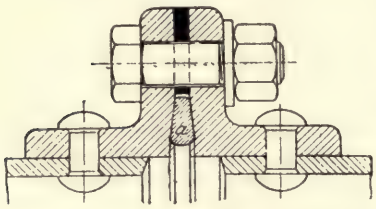


FIG. 5.—Type of Penstock Flange for Sillwerke, Innsbruck.

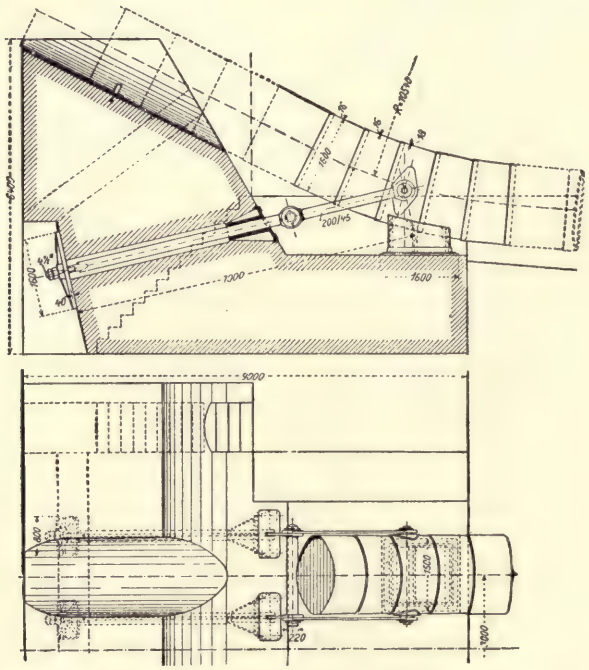


FIG. 6.—Method of Anchoring Penstock, Jajce Power Plant, Bosnia.

In the rear of the power house, a number of branch penstocks lead to the turbines. They are built tapered, and vary in thickness from $1\frac{3}{8}$ to $\frac{3}{4}$ of an inch. At the end of the last section of the penstock is a 28-inch gate valve for emptying the entire system when necessary. All branches are provided both outside and inside of the building with a gate valve.

Flanges. In connection with high-pressure penstocks, particular attention must be paid to the flanges uniting the different sections. In Fig. 4 are shown three different designs of flanges, as used with the previously mentioned Necaxa penstocks, for different pressures. It will be noticed that these flanges act as a lever upon the flared ends of the penstock.

Another type of flange, by the manufacturer of the above, will be found under subheading "Slip-joints." A simpler, yet efficient, flange joint is seen in Fig. 5. It has been used in connection with the Sillwerke plant, near Innsbruck, Tyrol. Its efficiency lies chiefly in the wedge-shaped packing.

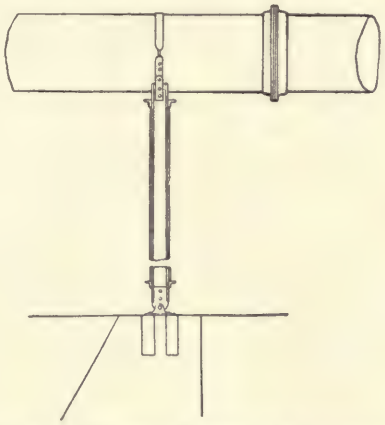
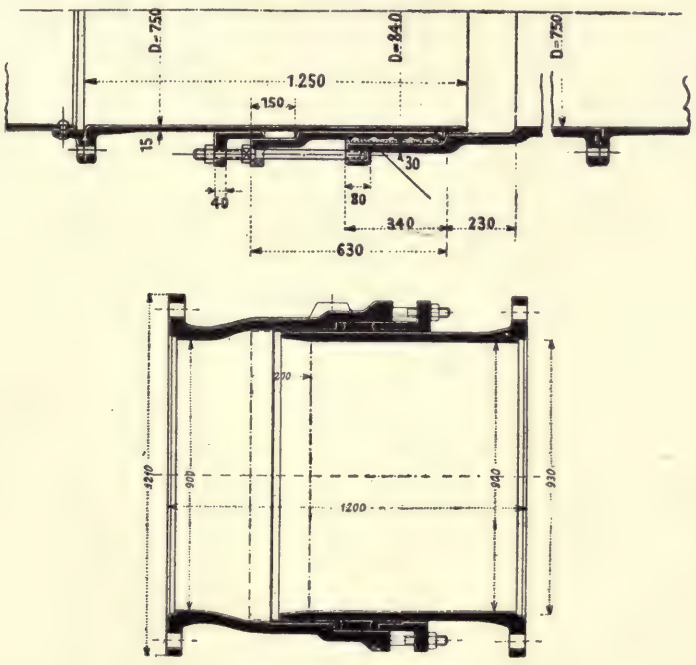


FIG. 7.—Hinged Penstock Support, Kaiserwerke, Tyrol.

Anchors. In order to prevent penstocks from sliding on mountain slopes, they must be anchored. The simplest way is to embed them in concrete blocks. Another way is to rivet on iron saddles, and bolt the same to concrete piers; in addition, anchor rods are sometimes used. Such a method of anchoring is seen in Fig. 6. By studying this illustration it will be readily seen that embedding the penstock in a single massive block would have accomplished the same purpose.



FIGS. 8 and 9.—Expansion Slip-Joints for Penstocks.

Special precautions must be taken, where the penstocks run on turns, either horizontally or vertically, by establishing fixed anchors. Between two anchors, the penstocks rest on supports, and an expansion joint must be provided.

Saddles. Penstocks must be properly supported between anchors on saddles, to allow the penstock, in case of expansion, to slide. As the movement of the penstock is slight, it is not essential to provide the saddles with rollers, as has been done in some cases. The saddles are made of cast iron or semisteel, and so designed, that the penstock rests on two carrying surfaces, in order to give a better support and minimize friction.

The saddles must be rigidly anchored to concrete or other masonry piers. The spacing of the saddles is closer at the bottom of the mountain slope than at the top, or they may be constructed heavier (similar to the penstocks) as the pressure exerted upon them is greater. When the penstock leaves the ground for short distances, a method for supporting may be adopted as is given in Fig. 6. It has been used in connection with a power plant in North Tyrol. It consists of a steel framework hinged to a concrete pier; the upper end forms a saddle, which is clamped to the penstock. This arrangement allows a free movement of the penstock due to expansion.

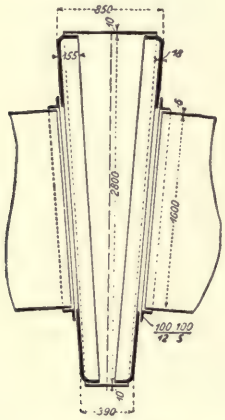


FIG. 10.—Wedge-Shaped Expansion Joint, Jajce Plant, Bosnia.

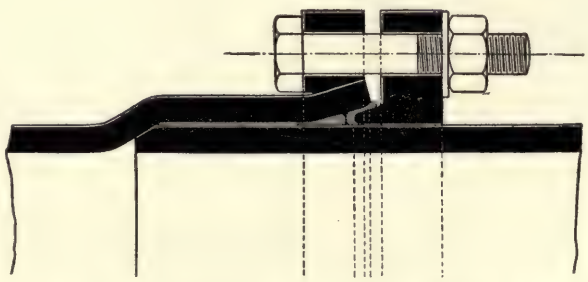


FIG. 11.—Ferrum Slip-Joint. Flange for High Pressure Penstocks.

Expansion Joints. The expansion joints must be located at the upper end of each section between anchors, when descending a mountain slope. This is done to relieve the expansion joint from the weight of the penstock, so that when expansion takes place, the section of the penstock slides up hill. These expansion joints are, in most cases, of the slip-joint type, as seen in Figs. 8 and 9, both of which have been used in connection with recent Swiss power plants.

Another type, seen in Fig. 10, has been used in connection with the Jajce plant in Bosnia. It consists of a wedge-shaped drum to take up the expansion of the penstock, which is laid on an angle. The diameter of drum depends upon the amount of expansion to be taken up, and the sides are preferably of copper.

A.E.&M.E.
UNIV. OF CAL.

A way to avoid special expansion joints and sliding saddles, is to use stuffing-box flanges, which have been used especially in high head installations. A detail of this flange joint is seen in Fig. 11. The manufacturers (Aktiengesellschaft Ferrum Kattowitz, Germany) claim that it is not essential to lay the penstock sections exactly on centers. It does away with slip joints, as each section takes up its own expansion. The joints can be packed without taking the sections apart. Because the flanges are removable, the sections are made easier for shipment, and in some cases they may be telescoped. Fig. 11 shows six penstock lines with this type of

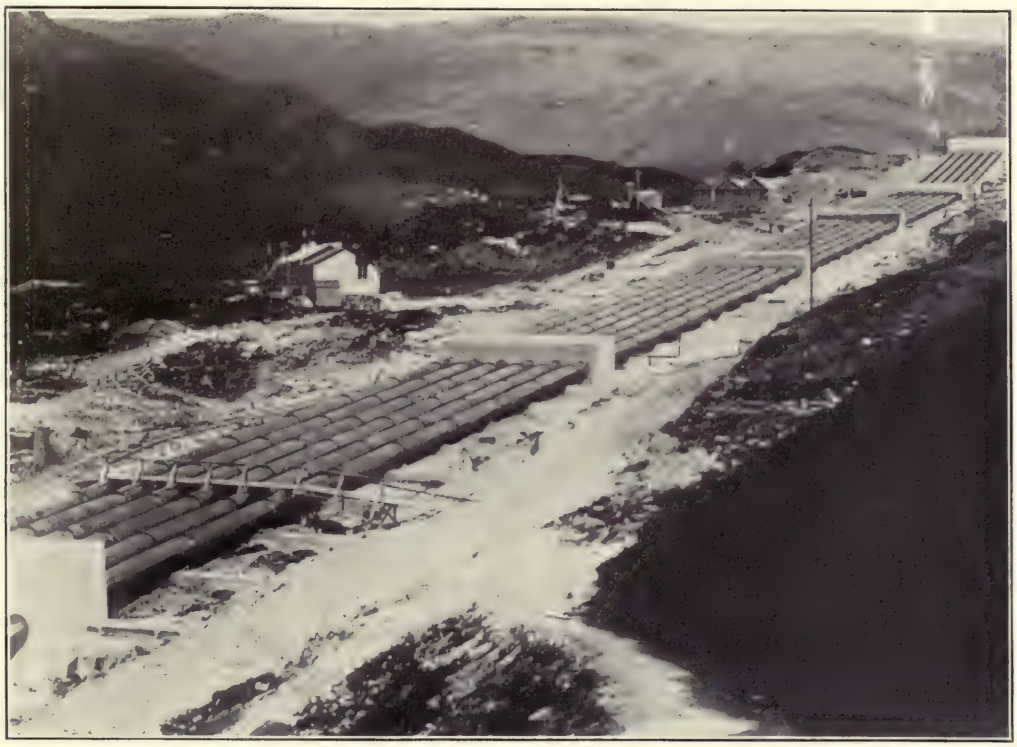


FIG. 12.—Penstocks with Slip-Joint Flanges, Loch Leven Plant, Scotland.

flange as installed for the Loch Leven Water and Electric Company, Scotland. These penstocks have a diameter of 40 inches, and a shell thickness varying from three-eighths to seven-eighths inch. The lower sections are designed for a pressure of 425 pounds per square inch. Each of the lines is 6230 feet long. The sections are made in 19.7-foot lengths. The concrete anchor blocks are placed about 175 feet apart.

The constant applied for calculating the expansion for wrought iron and steel is 0.0000067 of an inch per inch, or approximately .00008 of an inch per foot for one degree Fahr. The coefficient for cast iron is .0000059 per unit of length per degree Fahr. As cast iron or cast steel fittings amount to but little, the coefficient of wrought iron or steel is best employed.

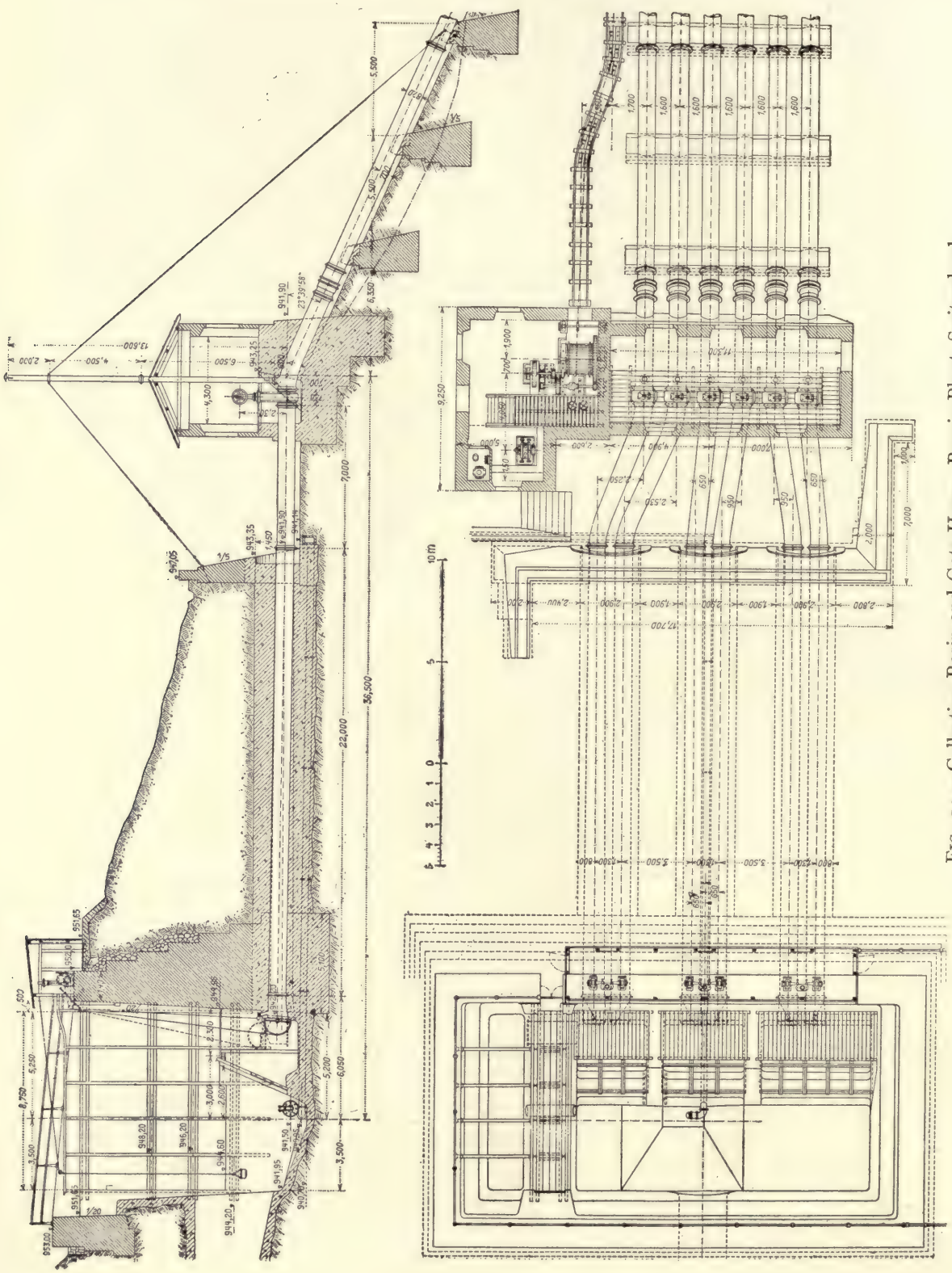


FIG. 13.—Collecting Basin and Gate House, Brusio Plant, Switzerland.

Safety Devices. For the protection of penstocks, they must be provided at the upper end with relief devices. If there is no air vent at the top, the penstocks are apt to collapse when the head gates are closed, because of the formation of a partial vacuum. This vent pipe is nothing more than a pipe connection on top and directly behind the head gate, and must extend above high-water level. Care must be taken that the vent pipes do not freeze. In many plants they are simply ducts in the wall of the collecting basin or dam. An example of such a device is given in Fig. 12, in which case there is a separate collecting basin and gate house. The vent pipes extend through the roof of the former and above the high-water level of the collecting

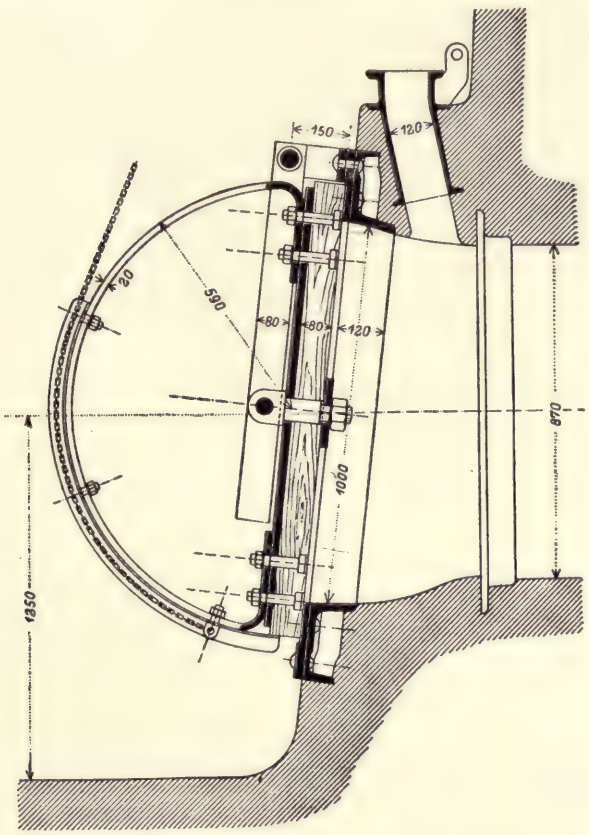


FIG. 14.—Automatic Flap. Inlet to Penstock, Brusio Plant, Switzerland.

basin. Another safety device in the head works of this plant is, the mouth of the penstock in the collecting basin is provided with a flap valve. In case a penstock should fail, this valve will close automatically, and can be operated from the collecting basin or from the power house by remote control. The flap is counterbalanced by a weight. The penstocks can be filled through a by-pass after the flap is closed (see Fig. 14). In addition to this, the collecting basin is provided with a mechanical-

electric water-level indicator, which indicates in the power house the water level in the collecting basin.

Another device for admitting air into a penstock to prevent the formation of a vacuum, is shown in Fig. 15. It has been installed in a recent Swiss power plant, which operates under a head of 767.5 feet. When the penstock is under pressure, the valve is closed; when air is admitted, the disk is held in place by a spring. In plants where the penstocks have a long horizontal run, and suddenly go down a steep slope, a vacuum will be created in the latter if the turbine valve is suddenly opened wide. This is due to the fact that the velocity will be greater in the vertical section than in the long horizontal line. To overcome this, the above-mentioned valve is placed near the junction of the vertical and horizontal sections.

Fig. 15 is another safety device, which will act automatically on low-water level, or in case the generator should drop its load. If for any reason the penstock should fail, the valve will shut off the water automatically.

The lower end of the penstocks must be provided with relief valves or blow-out plates, so that in case of a sudden shut down of the turbines, the water in the penstock will be released through the safety devices, and discharged into the tailrace.

The safety devices must be so located, that when they operate, no damage will result. Manholes must be provided on the lower sections of penstocks.

Standpipes. Another safety device, to relieve penstocks of excess pressure, is the standpipe. These standpipes are usually connected to the end of the penstock, and must extend vertically several feet above the head, so that in case of a sudden increase of pressure, the water has a chance to rise before overflowing. Usually these standpipes are wasteful, and to overcome this defect, a standpipe system similar to that in the Urfttalsperre, Germany, may be used. This standpipe, however, is not located at the end of the penstock, but lies at the junction of the pressure tunnel and the penstock.

Another method is to provide the lower end of the penstock with an air cushion, which is nothing more than a closed chamber, and acts in the same way as an air chamber on a reciprocating pump. This air chamber must be as air tight as possible, otherwise the air will escape and render the device useless. In connection with Jajce Power Plant, Bosnia, 1899, the author experienced similar trouble, and to remedy the difficulty, an air pump had to be installed to maintain the air cushion. All standpipes must be protected from freezing.

Protection. In exceptionally cold regions, penstocks must be protected from frost. They may be embedded in the ground below the frost line, or protected by a wooden box covering. To cite an example what frost might do, at Grand Mère, Quebec,[1] a penstock of 14 feet diameter was left unprotected during the first winter. It was found to have its interior surface covered with solid crystal ice of from 12 to 18 inches in thickness.

If the penstock is buried in the ground, the trench must be left open at least several months after operation has commenced, to ascertain whether additional

[1] Thurso, Modern Turbine Practice, p. 176.

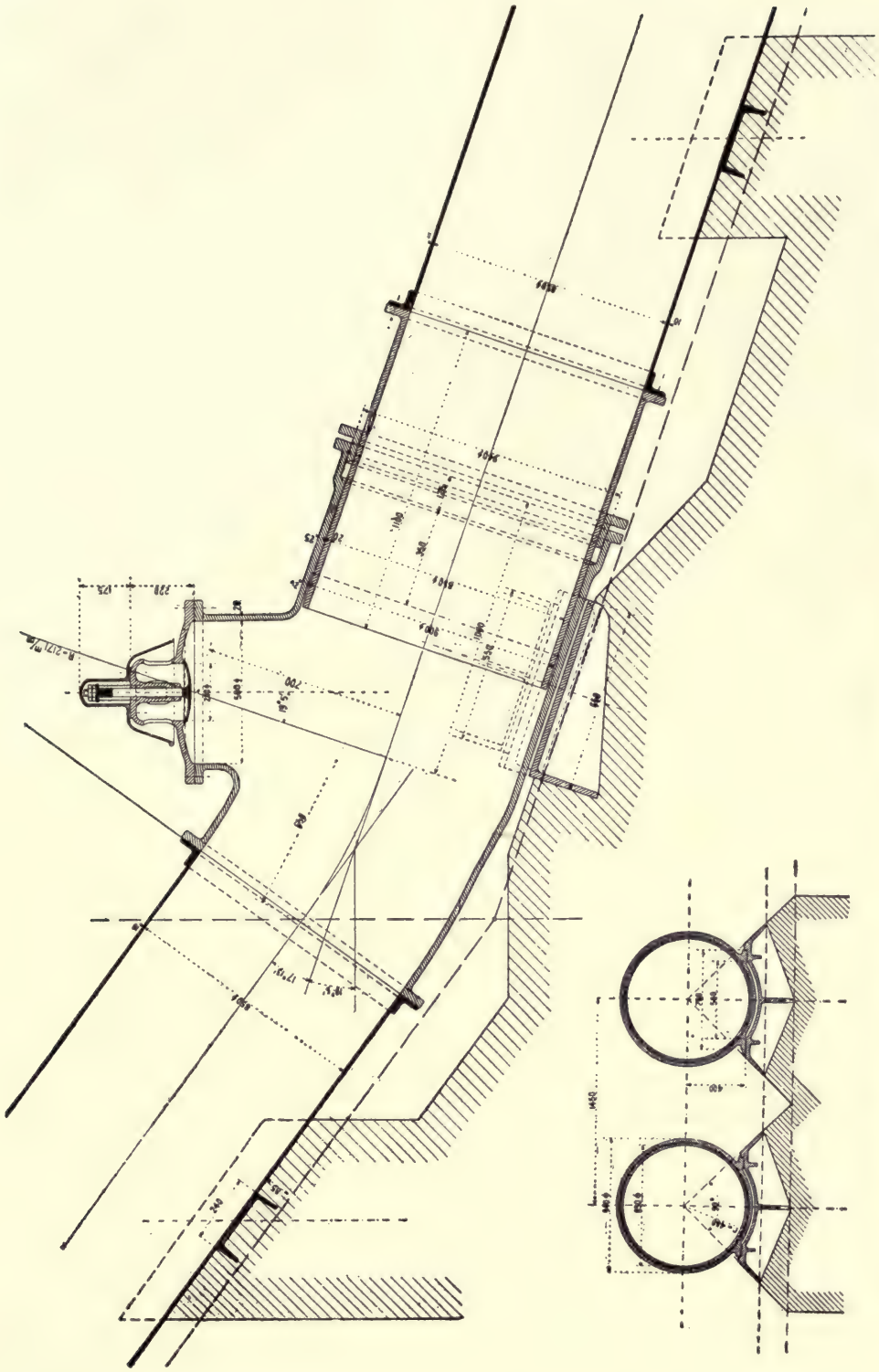


FIG. 15.—Vacuum Relief Valve in Penstock Run. Vandoise Motor Power Company's Plant at Lakes of Joux and Orbe.

calking is necessary. Before the trench is filled, the penstock must be properly painted. Buried penstocks do not require any device for taking up expansion.

All penstocks must be coated with hot asphalt both inside and outside.

WOODEN PENSTOCKS.

Adaptability. Wooden penstocks are largely used in the western states, particularly on the Pacific coast, where it is necessary to conduct water over long runs. They are practically installed for heads up to 300 feet. Wherever they are installed under higher heads, they are always placed in the top section of the conduit. As they have many advantages over metal or reinforced concrete penstocks, they are much in favor. Some of the advantages are, that they are smooth and have a greater carrying capacity, ranging from 10 to 20 per cent more than any other. Another important factor is, that they are very much cheaper and do not deteriorate as rapidly as those of metal. Further, they are unaffected by frost.

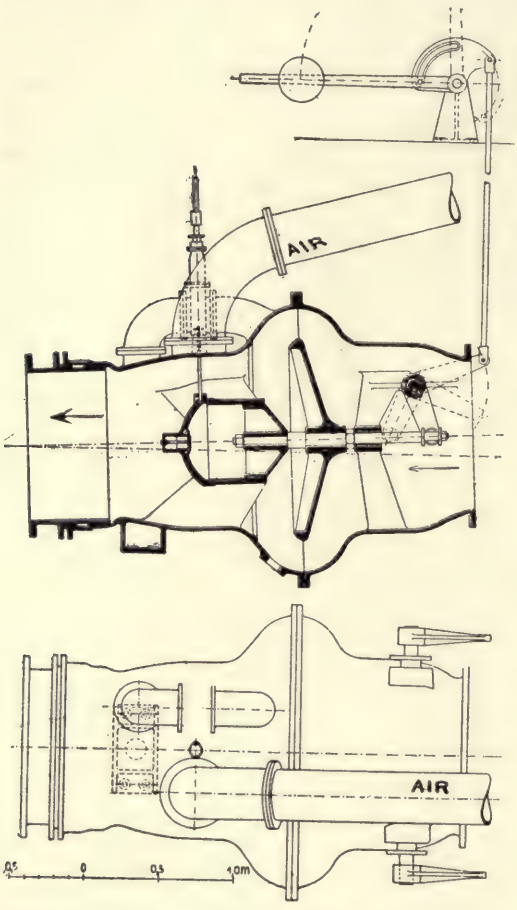


FIG. 16.—Automatic Low Water Device for Protecting Penstocks.

In the construction of some penstock lines, it would be difficult to transport heavy steel penstocks over the country where there are no roads. In such cases, the wooden penstock is used. They range in diameter from 10 inches upward, and vary in thickness according to the diameter. The staves are milled from clear, well-seasoned or kiln-dried yellow pine, redwood or fir. The ends of the staves are connected by a tongue, which prevents butt joint leakage. The staves are held in place by steel rods and a cast-iron shoe.

Spacing of Bands. The spacing of the iron bands is determined by a formula given by James D. Schuyler.[1]

$$N = \frac{1200\ DP}{2\ S}.$$

N = number of bands per 100 feet.
D = diameter of pipe in inches.
P = pressure in pounds per square foot.
S = safe working strain in pounds per square inch for bands when threaded for use, determined by regular tests at the mills where they are made.

[1] *Trans. of Am. Soc. of C. E.*, vol. XXXI.



FIG. 17.—84-inch Wooden Stave Penstock, 3700-feet long, joined to two 60-inch Riveted Steel Penstocks, each 800 feet long. Trenton Falls Water Power Plant, Utica, New York.

The following values of S give a factor of safety of about five in each case, or about one-fourth of the elastic limit:

TABLE I. — SAFE WORKING STRAIN OF PENSTOCK BANDS.

$\frac{3}{8}$-inch bands.....	plain	$S =$ 1000 pounds.
$\frac{3}{8}$-inch bands.....	upset	$S =$ 1200 pounds.
$\frac{1}{2}$-inch bands.....	plain	$S =$ 2000 pounds.
$\frac{1}{2}$-inch bands.....	upset	$S =$ 2500 pounds.
$\frac{5}{8}$-inch bands.....	plain	$S =$ 3000 pounds.
$\frac{5}{8}$-inch bands.....	upset	$S =$ 3500 pounds.

The formula given below was used by C. P. Allen, in the construction of a $6\frac{1}{2}$-mile penstock along the Little Conemaugh River near Johnstown, Penn. This penstock has a diameter of 36 to 44 inches. The pressure in this penstock is slight; the regular slope is 1 to 2 feet in 1000.[1]

[1] Some Applications of Wooden Stave Pipe, by John Birkinbine, in a paper before the Engineers' Club, Philadelphia, Penn.

$$\text{Number of bands per 100 feet} = \frac{600\ DPHF}{AB}.$$

D = diameter of pipe in inches.
P = pressure due to 1 foot. (0.44 pound.)
H = head in feet.
F = factor of safety.
A = area of bands in square inches.
B = breaking strain of bands per square inch.

Thus, for a 44-inch penstock, one-half inch bands, and a 50-foot head, the number of bands per 100 feet is

$$= \frac{600 \times 44 \times 0.44 \times 50 \times 4}{0.19635 \times 60000} = 197.$$

Friction. As already indicated, the friction in wooden penstocks is very low, as the staves are planed. The resistance of steel penstocks increases each year, while that of wooden penstocks decreases. In Kutter's formula, the factor of resistance is generally taken as 0.010 for wooden stave pipe, while for steel as 0.013. Sometimes the factor for wooden stave penstocks goes as low as 0.007.

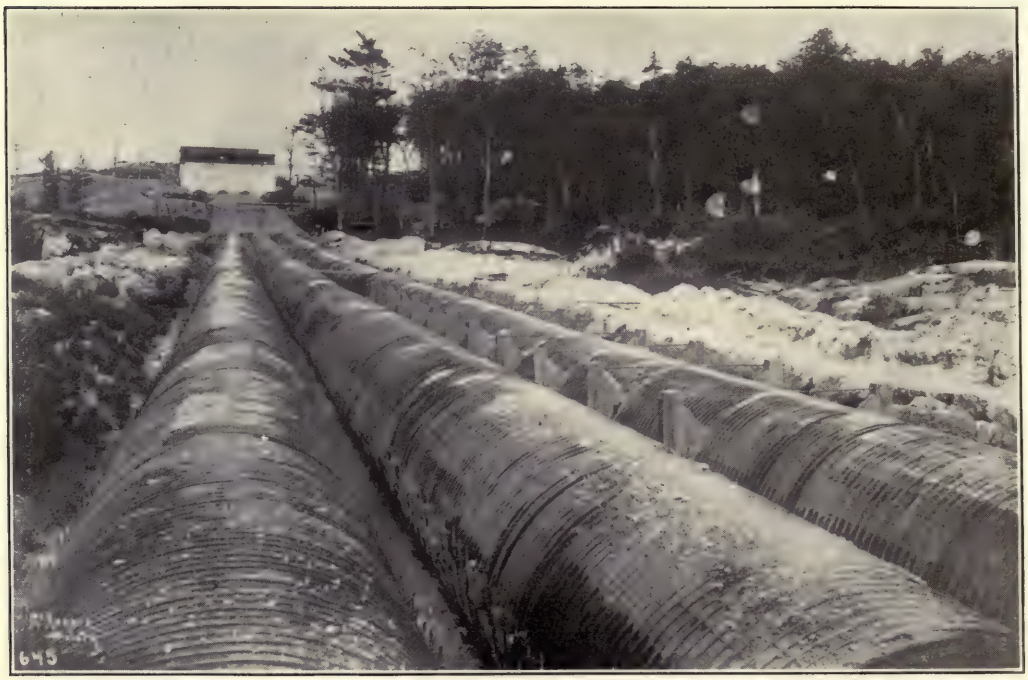


FIG. 18.—Three 7-foot Wooden Stave Penstocks, each 4000 feet long and connected to Riveted Steel Penstocks, 1000 feet long. Great Northern Power Company, Duluth, Minnesota.

Durability. The durability of wooden stave penstocks if kept continually wet, is yet undetermined. The following data are of interest: in 1898 some of the original

wooden pipe laid in the London waterworks in 1802, were taken out sound and free from rot. Some of these wooden mains were in actual use as late as 1865, after having been in the ground for 63 years. Some of the wooden pipes first laid in Philadelphia, after being in use 21 years, were removed and relaid in Burlington where they were in use for 28 years.

In a series of tests carried on at the Puget Sound Navy Yard in 1901, comparing Douglas fir and yellow pine for pipe staves, Frank W. Hibbs, naval constructor of the United States Navy, arrived at the following conclusions:

In strength, Douglas fir is generally equal to yellow pine, and superior to it in some essential particulars.

Douglas fir is decidedly more elastic than yellow pine.

Douglas fir is far superior to yellow pine as regards toughness.

Yellow pine is superior to Douglas fir in wearing qualities, especially when moisture is present.

Yellow pine is superior to Douglas fir in lasting qualities, on account of the greater amount of pitch it contains.

Douglas fir is 14 per cent lighter than yellow pine.

Following are the average general characteristics of strength of Douglas fir:

For well-seasoned, fine-grained, hard, clear stock:

TABLE II. — STRENGTH OF DOUGLAS FIR.

Characteristics.	Pounds per square inch.
Tensile strength	13,000
Tensile strength across grain	350
Tensile strength for bending	10,000
Elastic limit for bending	6,000
Modulus of elasticity for bending	1,500,000
Strength for compression across the grain without destructive deformation	1,200
Modulus of elasticity for compression across the grain.	4,000
Crushing strength for compression, "end on" to grain	9,000
Modulus of elasticity for "end on" compression	70,000
Modulus of elasticity for torsion	27,000
Shearing strength with the grain	15,000
Crushing strength for columns whose proportions are such as to resist bending	6,000
Weight per cubic foot, pounds	35

Cost. The cost of wooden stave penstocks relative to steel penstocks, depends on pressure, size, location, and character of country, through which they are laid. Mr. L. A. Adams states that the details of cost of an 18-inch penstock at Astoria, Ore., 7½ miles long, are as follows:

"Steel in bands, $0.048 per pound; lumber, feet board measure in staves measured before milling, $35.40 per thousand. The cost to the city, including all appurtenances, was $0.903 per foot; and $0.76 excluding such appurtenances. The whole amount of the contract was $36,100, and the total extra work cost, $29.35.

The distribution of the cost was as follows:

"Building and spacing bands, 55 per cent; back-cinching, 26 per cent; repainting ironwork, 3 per cent; back-filling to a depth of 6 inches over the pipe, 8.75 per cent; placing specials, 3.5 per cent; placing air valve, 0.75 per cent; unclassified labor, 3 per cent."

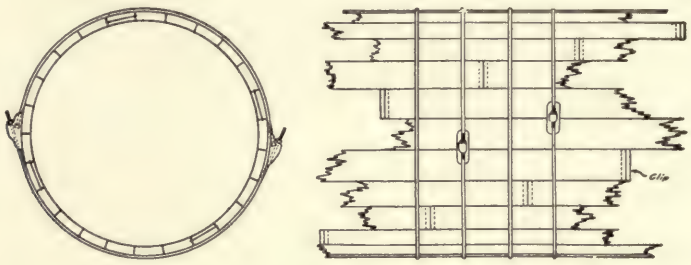


FIG. 19.—Cross Section and Partial Plan of a Wooden Stave Penstock.

Adams also gives the cost for the riveted steel pipe in the same line as follows:

Size.	Gauge of steel.	Price.
14-inch	No. 12	$1.10
16-inch	No. 12	1.18
16-inch	No. 10	1.38

The manufacturing cost of the riveted steel pipe was about 0.45 of a cent per pound for labor only, including the cost of dipping.

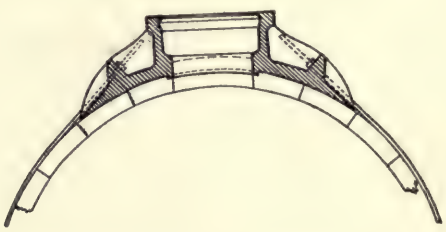


FIG. 20.—Cast-Iron Saddle for Connection to a Smaller Pipe.

Comparative costs on the construction of steel, cast-iron and wooden penstocks are given in Table III, as compiled by Mr. A. L. Adams for Chicago. These figures are supposed to include only the principal items, with no profit to the contractor, or for incidentals, and are therefore for comparison only.

TABLE III. — COMPARATIVE COST OF PIPE AT CHICAGO, INCLUDING LAYING, BUT OMITTING HAUL.

Wooden Stave Pipe.

Diameter.	25-foot head.	50-foot head.	100-foot head.	200-foot head.
Inches.				
12	$0.42	$0.49	$0.63	$0.85
18	0.69	0.80	1.02	1.46
24	0.79	0.91	1.14	1.61
30	0.96	1.12	1.44	2.06
36	1.19	1.40	1.82	2.65
42	1.40	1.68	2.23	3.33
48	1.55	1.85	2.46	3.67
54	2.23	2.62	3.43	5.02
60	2.85	3.35	4.37	6.40
66	3.21	3.81	5.00	7.38
72	3.65	4.38	5.83	8.73

Riveted Steel Pipe.

Diameter.	No. 14.	No. 12.	No. 10.	No. 8.	No. 6.	¼-inch.	5/16-inch.	⅜-inch.
Inches.								
12	$0.32	$0.38	$0.44	.....	.....	.....	.....	.....
18	.....	0.57	0.65	$0.78	$0.98	.....	.....	.....
24	.....	.....	0.85	1.04	1.28	$1.55	$1.99	.....
30	.....	.....	.....	1.27	1.59	1.93	2.46	$3.04
36	.....	.....	.....	1.55	1.93	2.30	2.92	3.58
42	.....	.....	.....	1.61	2.18	2.66	3.37	4.12
48	.....	.....	.....	.....	2.48	3.03	3.83	4.66
54	.....	.....	.....	.....	2.80	3.41	4.29	5.21
60	.....	.....	.....	.....	.....	3.79	4.75	5.74
66	.....	.....	.....	.....	.....	4.35	5.21	6.29
72	.....	.....	.....	.....	.....	4.52	5.66	6.83

Cast-Iron Pipe.

Diameter.	25-foot head.	50-foot head.	100-foot head.	200-foot head.
Inches.				
12	$0.73	$0.77	$0.84	$1.00
18	1.29	1.35	1.46	1.70
24	1.91	2.00	2.18	2 55
30	2.67	2.80	3.07	3.61
36	3.47	3.67	4.06	4.85
42	4.42	4.69	5.22	6.28
48	5.50	5.84	6.53	7.92
54	6.65	7.10	8.00	9.78
60	8.04	8.63	9.80	12.13
66	9.51	10.16	11.55	14.05
72	11.32	12.00	13.26	16.00

Construction. A very good example of wooden stave pipe construction is that built in connection with the Bishop Creek Power Plant.[1] The penstock is about 12,000 feet long, consisting of 6700 feet of 42-inch wood-stave pipe, 2150 feet of 30-inch wood-stave pipe, and 3150 feet of 24-inch steel penstock; all diameters being inside measurements. The 42-inch penstock lies on a nearly level grade, the static head at the lower end being about 30 feet. At this point, are placed two 30-inch gate valves, one opening into the 30-inch penstock, and the other provided for a future line. The 30-inch penstock descends the hill to a point that gives a static head of 265 feet. Here it joins the 24-inch steel penstock, which descends a steep hill to the power house; the total static head is 1068 feet. For about 500 feet, this steel penstock is laid on an angle of 38 degrees from the horizontal.

The 42-inch penstock is made up of twenty-five staves, and the 30-inch penstock of nineteen staves, milled from a 2 by 6-inch piece. The lumber is red fir from Southern Oregon, and the staves were milled there to the proper circle. The bands are mild steel, one-half inch in diameter, with ends upset to five-eighths inch diameter. They were shipped straight, and bent to form at the work. The lugs are of cast iron, of a form that allows the ends of the bands to pass each other, and be tightened with nuts on each end.

When the bands are tightened there is a slight bending of the rods, but this is not believed to be injurious. The ends of the staves were slotted, and a three-sixteenths by one-half inch compressed paper dowel inserted. When wet, this dowel swells, and proves very effective in closing leaks. Bands on the 42-inch penstock were spaced on 6-inch centers, although the pressure did not demand this close spacing. On the 30-inch pipe, which is subject to a considerable pressure, the designer used the pressure due to swelling of wood given by A. L. Adams, 100 pounds per square inch; in addition to this, an allowance was made for initial tension in the rods due to the stress necessary to bring the staves into form. Red fir is a very stiff wood, and by observation it was determined necessary to use 2100 pounds to bring the staves into position; this was calculated as being distributed along the lineal foot of pipe, and distributed among whatever number of bands occurred in that length under different heads. Bands were spaced under these assumptions with a safety factor of four.

The question of initial tension on the rods is believed to be a vital one, as, in the case of the stiff lumber used, it required much cinching to make the staves come together. As the wood is hard, the bands crushed into it but little under pressure, and hence there is little relief to the stress. By test it was determined, that, with the wrenches used, an initial tension of 8000 pounds per square inch could easily be obtained.

The wood pipe is laid directly on the ground, a few sills of culled material being placed at intervals. At points, it was covered with earth as a protection from possible rocks rolling down the steep hillsides. The penstock was laid in easy curves, but in one case a curve of 100 feet radius was made through nearly 90 degrees. For nearly two months the daily amount laid averaged 110 feet.

[1] Bishop Creek, Cal., Hydro-electric Power Plant, by J. D. Galloway. *Electrical World*, June 30, 1906.

The wood pipe is provided with two 6-inch and one 30-inch standpipes, the former being of casing and the latter of 30-inch wood pipe. In addition, 6-inch air valves are supplied in such number, that there is a 6-inch opening every 1100 feet. On the steel pipe, three 6-inch air valves were placed at the upper end. The material for the wood pipe was mostly hauled to the site on wagons, a minor portion being hauled up from the power house on the tramway used in laying the steel pipe.

Another very interesting, and in some respects difficult, wooden stave penstock construction was laid in the American Fork Canyon, Utah.[1] Where conditions justified, the continuous wood-stave penstock was laid on a grade as near the hydraulic grade as was thought advisable, when considering the necessity of keeping the pipe filled. It was found necessary, however, to construct three inverted siphons, the first and longest one being at the upper end of the line, where the pipe follows down the bottom of the canyon for some distance; the other two are about midway between the point of diversion and the power house. The maximum head on this pipe, at one of the siphons, is 175 feet.

The remaining portion of this line was laid on a table, cut on a grade contour along the mountain side. As the canyon is rough and broken, this alignment necessitated the introduction of many curves, some of which were quite sharp, and the driving of many tunnels through solid quartzite ledges, the length of the tunnels varying from 25 to 160 feet. The tunnels were rectangular in shape, the dimensions being 4 by 5 feet, and some of them were located on curves.

The pipe is 36 inches in diameter, and a section at right angles to its axis shows 22 staves. These staves were sawed from well-seasoned Oregon fir, with their faces dressed to true segments of circles, and the edges to true radial lines. They are 1⅝ inches thick, but vary in length from 8 to 15 feet.

In making the joints, a special malleable casting patented by Frank C. Kelsey was used. A section through this casting is similar in shape to that of an I-beam, except that there is a shorter flange projecting from the middle of the web on either side. The distance between the outer edges of the main flanges corresponds with the thickness of the staves, but one of them has a batter of one-thirty-second inch. This means, that when in place, the outer flanges project over the ends of the stave, compressing it one-thirty-second inch, while the middle triangular flanges are driven into them. The flanges of this casting are longer than the web, so they not only project over the two ends of the staves, but also over the side adjoining.

The bands are one-half inch in diameter and have square heads, with upset threaded ends. The foreman on the work was provided with a sheet showing the required band spacing for the various portions of the pipe, the spacing having first been calculated for the given pressure.

The coupling has a curved seat, which sets on the outside of the stave, and two lugs so designed that they will hold both the head and nut of the band.

The staves were hauled as near to the work as possible in wagons. From this point, in the bottom of the canyon, a narrow T-rail track was laid up the mountain

[1] An Hydro-electric Development in American Fork Canyon, Utah, by A. P. Merrill. *The Engineering Record*, May 9, 1908.

side to the grade. The cars containing the bands, staves, and so forth, were drawn up the track by a horse.

All castings and steel bands were dipped in a special paint before being used. This was done in the bottom of the canyon near the lower end of the track.

Construction was quite difficult in many places, especially at the two lower siphons, and in the tunnels located on the curves. In building the pipe around curves, short straight lengths from 50 to 75 feet long were first constructed, only enough bands being used to hold the staves in place. It was then shifted into the proper place with jacks. In doing this, some of the staves tended to slide longitudinally, which condition required driving them to place, from the end of the pipe, with heavy mallets. The rest of the required number of bands were then placed.

When the bands were first placed around the dry staves, they were made just tight enough to hold the pipe together. After the water had been turned in, and the staves had become fairly well saturated, all bands were tightened. But at no time were they drawn so tight that the fiber of the wood was cut or crushed. The second tightening of the bands stopped practically all leaks, there being none in the two miles of pipe of any importance, and only a small number of minor ones where the pressure was highest.

Air vents or standpipes were placed at all summits, and washout valves at the lowest point in the siphons. Much of the sediment that succeeds in passing the headworks will settle in the siphons, where it can be washed out, and its deteriorating effects on the machinery avoided.

REINFORCED CONCRETE PENSTOCKS.

The reinforced concrete penstock has not been used to a great extent, although, in some French plants, they have been used for many years under low heads, and are made in one continuous piece by hand.

A newer process (System Siegwart) has been developed in Switzerland, whereby penstocks of reinforced concrete can be made by machinery, and capable of carrying pressures up to 300 pounds and higher, if desired. The thickness of the shell is a matter of requirements to suit the conditions at hand.

Being manufactured by automatic machinery of very compact design, the penstocks can be readily made in the field. They are made in sections, the length of which depends on the size of the machine. The ends are provided with special joints, which, after in place, are filled with asphalt. To insure further tightness, an external band is slipped over the joint, and sealed by the asphalt.

After coming from the machine, the penstock sections are coated inside with a layer of asphalt. This treatment renders the penstock absolutely water tight, and, in addition, reduces the skin friction, which means an increase in head above the ordinary concrete penstock.

A.E.&M.E.
UNIV. OF CAL.

BIBLIOGRAPHY.

EXPERIMENTAL STUDY OF THE RESISTANCE OF THE FLOW OF WATER IN PIPES. A. V. Saph and E. W. Schoder. *Proc. A. S. C. E.*, May, 1903.

FLOW OF WATER IN WOODEN PIPES. T. A. Noble. *Trans. A. S. C. E.*, vol. 49, 1902.

FLOW OF WATER IN PIPES. C. H. Fulton. *Journal Association Engineering Societies*, October, 1899.

FRICTION COEFFICIENT OF RIVETED STEEL PIPES. A. McL. Hawks. *Proc. A. S. C. E.*, August, 1899.

A TRAVELING MOLD FOR MAKING REINFORCED CONCRETE PIPES. F. Teichman. *Engineering News*, Feb. 20, 1908.

PIPE LINES FOR HYDRAULIC PLANTS. *Engineering Record*, Dec. 21, 1907.

A DIAGRAM FOR CALCULATING PENSTOCKS. Richard Muller. *Engineering Record*, Nov. 14, 1908.

PENSTOCKS FOR WATER POWER PLANTS. Frank Koester. *Engineering Record*, Feb. 20, 1909.

WOODEN STAVE VS. RIVETED PIPE. *Journal Association Engineering Societies*, p. 239. 1898.

STAVE-PIPE. A. L. Adams. *Trans. A. S. C. E.*, p. 676. 1898.

CHAPTER V.

POWER PLANT.

GENERAL ARRANGEMENT.

HYDRAULIC power plants have no standard arrangement, as there are so many types of turbines which are fed under various conditions; low heads may be utilized by horizontal or vertical turbines, requiring an entirely different proposition in the layout of the plant. The same is true for average as well as high head turbines; even in the latter case, which usually requires horizontal impulse wheels, vertical impulse wheels are sometimes used. Whatever arrangement is chosen, care should be exercised to locate the turbines so as to secure the highest possible head. Many turbines are dependent upon draft tubes to give additional heads. The turbines and regulators should be set in straight lines, and not scattered about the generating room. This also applies to high head turbines which are sometimes set on 45 degrees, which is done to give a more easy penstock connection. Such arrangements can be easily overcome by exercising a little judgment, and with little or no expenditure of money. This must be done for the sake of the appearance of the plant, and, of still greater importance, ease of operation. Whatever arrangement is decided upon, the flow of water to the turbines should be as free and easy as possible, to avoid friction.

Heads utilized vary very greatly. At Genoa, Switzerland,[1] is a plant utilizing a head of 16.5 inches, while at Vouvry on Lake Geneva, Switzerland, there is a 20,000-HP. plant operating under a head of 3116 feet.[2]

From the foregoing figures, it will be seen that it is impossible to delineate the different designs of plants operating under various heads and conditions. In the following pages, only a few typical arrangements of low, medium and high head plants are discussed. In low and medium plants, the power house frequently forms a part of the dam, or adjoins the dam on the downstream side, or, in the case of a hollow concrete dam, is located in the body of the dam. In any case, the walls must be made waterproof to prevent seepage leaking into the power house.

Forebays. Forebays must be located so as to deflect all foreign material as much as possible. This is best done by placing the deflecting wall at an angle of 30 to 45 degrees to the flow of the stream. This wall extends 2 or 3 feet into the water. Below the water level and fastened to the deflecting wall are rough screens, which in large plants consist of heavy bars. The forebay itself should be provided with a spillway, icerun and a sandtrap. The latter is best located just before the water enters the penstock. The bottom of the forebay must slope towards the sandtrap,

[1] Thurso, Modern Turbine Practice, p. 13.

[2] Wagenbach, Turbinenanlagen, p. 3.

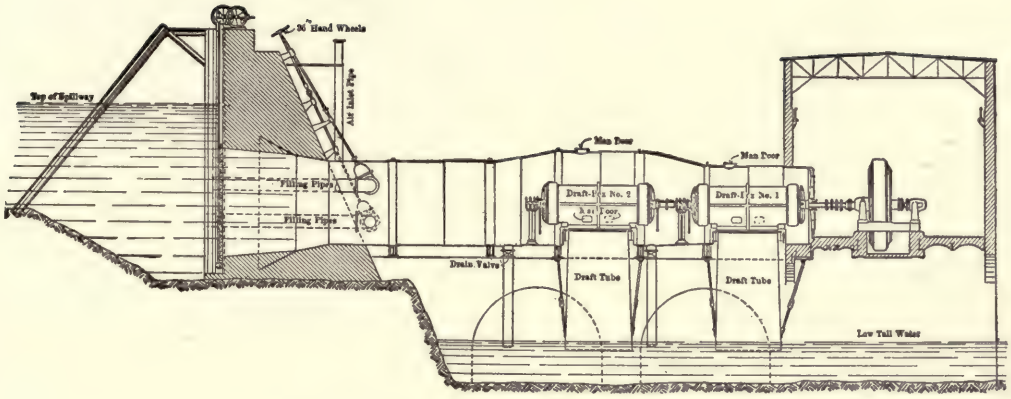


FIG. 1.—Winnipeg, Manitoba, Plant.

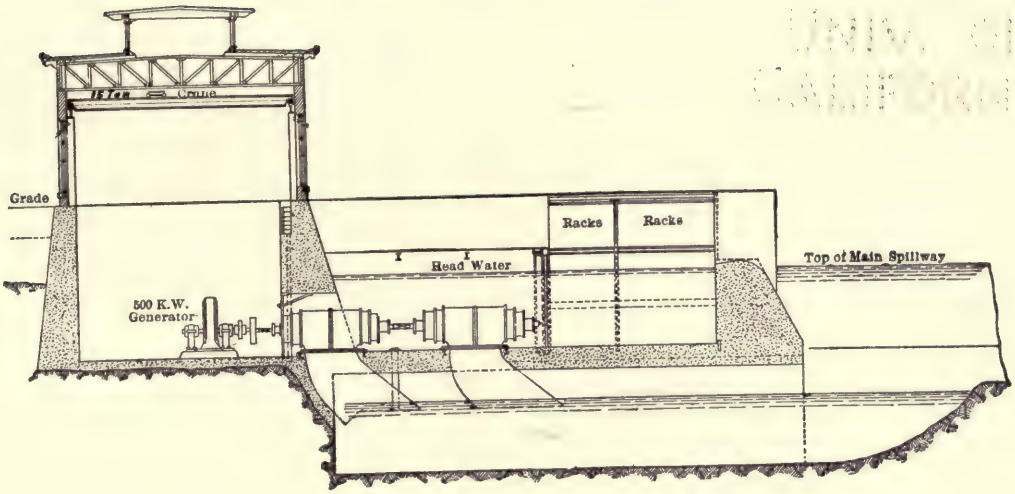


FIG. 2.—Cross Section of Albany, Georgia, Plant.

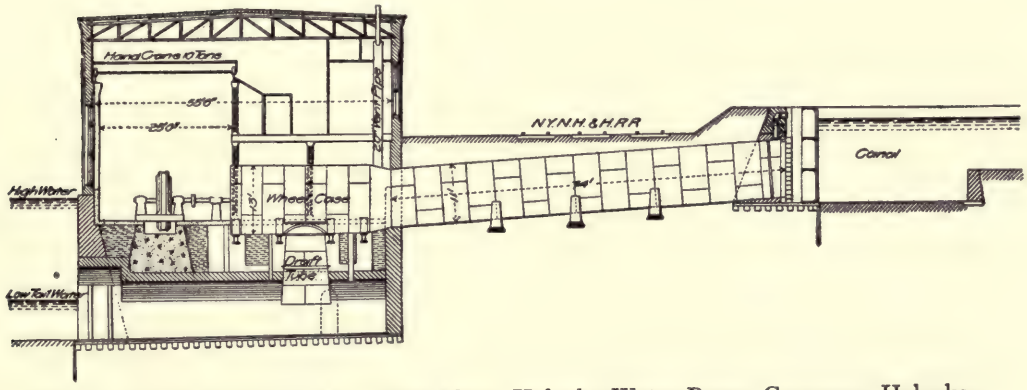


FIG. 3.—Cross Section of Low Head Plant, Holyoke Water Power Company, Holyoke, Massachusetts.

to decrease the velocity of approach, and to give the sand and gravel an opportunity to settle. There must be an opening on the spillway side, to carry off the stuff which has collected in the trap. The penstocks must be provided with fine screens located above the sandtrap and in front of the penstock openings. In large plants, the screens and gates to the penstocks are usually placed in a house by themselves, which is provided with a crane to remove and lower screens. In temperate zones, it is advisable to install a heating system in the screen and gatehouse, for the prevention and thawing of ice.

The design and arrangement of the forebay, in connection with the power house, depend upon nature and character of stream, particularly on the nature of the floating material; also the formation of ice is an important factor in this consideration.

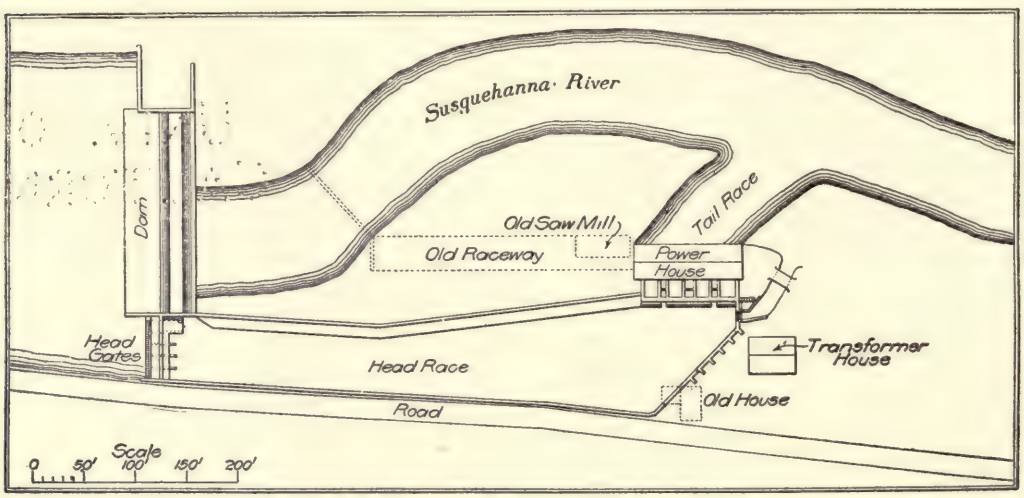


FIG. 4.—General Plan of Colliersville Plant, Oswego County, New York.

Low Head Plants. Low head turbines are usually located in open flumes, with vertical or horizontal shafts. With the vertical shaft, frequently several turbines are connected, by gearing, to one horizontal shaft. With this arrangement, special precaution must be taken to exclude moisture from the generating room.

Fig. 1 shows the power plant of the Winnipeg Electric Railway Company, which utilizes water from the Winnipeg River, some 65 miles from the city of Winnipeg, and transmits the power at 60,000 volts.[1] A channel had to be cut to the Upper River near the Otter Falls, 120 feet wide, with a clear depth of 8 feet at normal low water; the channel is 8 miles long with a drop of 5 feet to the mile, thus giving a head of 40 feet. The units are McCormick turbines coupled to 1000-K.W. generators, making 200 R.P.M., and are equipped with Lombard governors.

It will be noticed that two pairs of turbines with two draft tubes are located in one casing, which is an extension of the penstock. The gates to the penstock are

[1] Winnipeg, Manitoba, 60,000-Volt Hydro-electric Plant, by V. D. Moody. *Electrical World*, June 23, 1906.

provided with by-pass or relief valves, to facilitate the operation of the main gate.

Fig. 2 gives the power house cross section of the Albany Power and Manufacturing Company, located on Big Shoals on the Muckafoonee River, about one mile below the city of Albany, Ga.[1] For utilizing the water, a dam 360 feet long and 20 feet high, and a spillway 150 feet long, have been erected. The turbines are of the horizontal, radial, inward flow type, made by the S. Morgan Smith Company. Each unit comprises four wheels, 33 inches in diameter, mounted in a cast-iron housing.

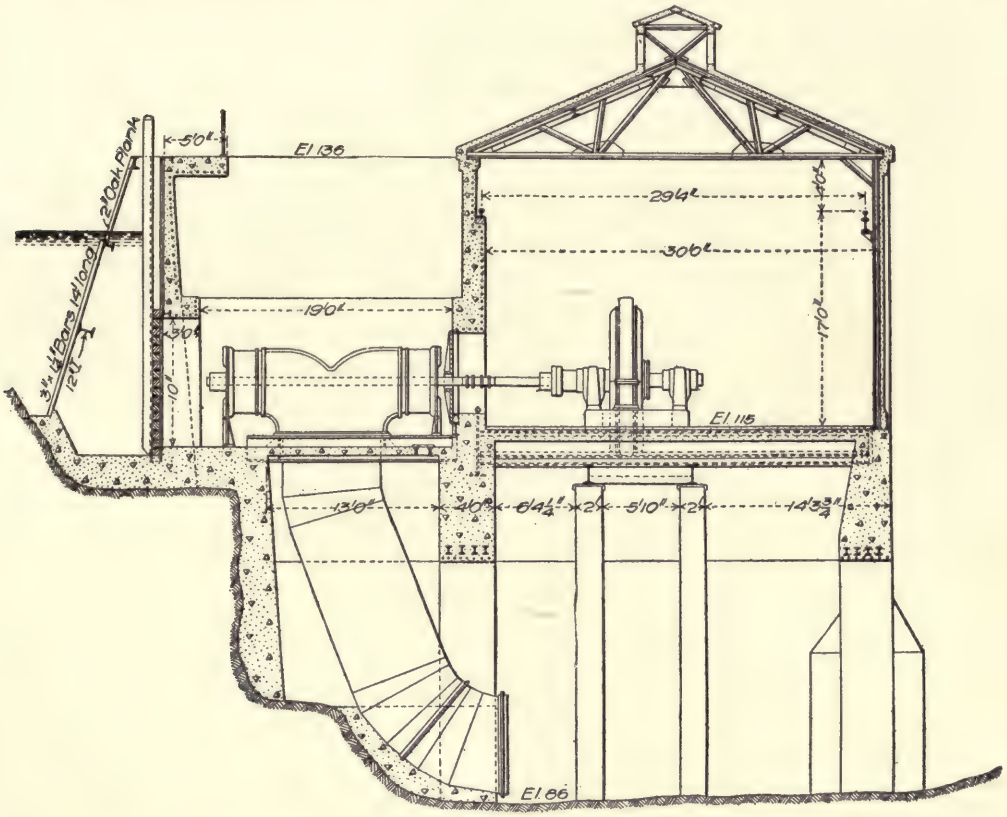


FIG. 5.—Cross Section of Colliersville Plant, Oswego County, New York.

The discharge through each pair of turbines passes through a draft tube 7 feet 9 inches in diameter, made of one-quarter-inch steel plate. The head on the turbines is 23 feet, and each unit is capable of developing 900 HP. at full gate. They are controlled by Lombard governors, and connected to 500-K.W. generators.

Medium Head Plants. Medium head plants are usually equipped with Francis turbines of the horizontal or vertical type. When the horizontal type is chosen, there is usually only one wheel mounted on the shaft coupled to the generator, and supplied by a closed penstock. The unit must be set above ground water. With the adoption

[1] Hydro-electric Plant at Albany, Ga., by R. W. Hutchinson, Jr. *Electrical World*, June 16, 1906.

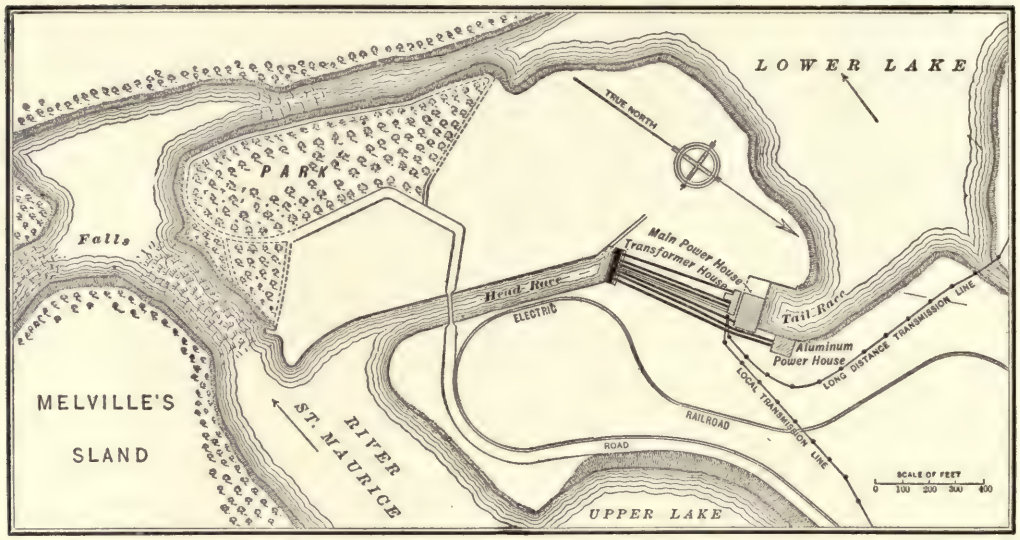


FIG. 6.—Map of the Shawinigan Power Plant, showing Arrangement of Headrace and Power House.

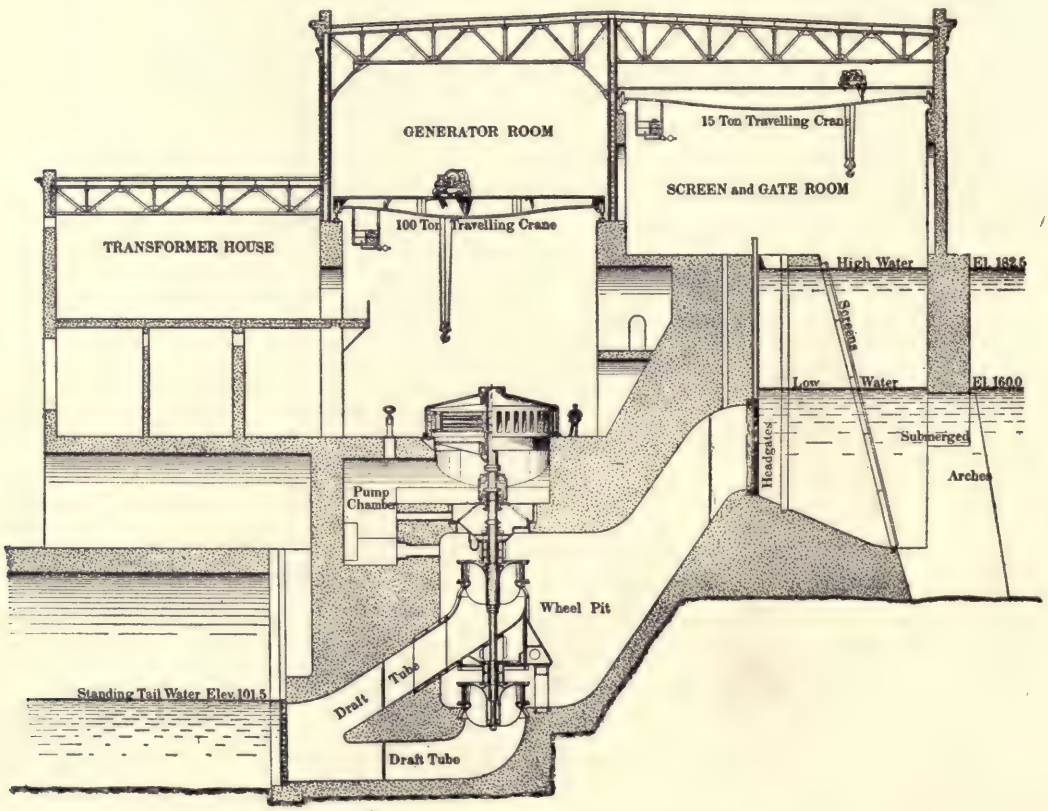


FIG. 7.—Cross Section of McCall Ferry Power House.

of the vertical shaft turbine, in almost all cases, there is more than one wheel mounted on the shaft, and they are located in an inclosed wheel pit, or else in a steel or iron casing. The intake and draft tubes to and from the wheel pit must be smooth, particularly when made of concrete. All intakes must be provided with vent pipes.

Fig. 7 shows the general arrangement of the turbine, generating and transformer rooms of the McCall Ferry Power Company's plant. The plant is located on the Susquehanna River, about 25 miles from Chesapeake Bay, and is designed for a normal capacity of 100,000 HP., half of which at present is being installed. The dam is 75 feet high and 2500 feet long. The turbines, furnished by the I. P. Morris Company, are of the inward and flow Francis type, mounted in pairs on a single shaft. At a speed of 94 R.P.M., a head of 53 feet, and with a gate opening of 80 per cent, they are capable of developing 13,500 HP. The turbines are connected to 7500-K.W., 25-cycle generators.

The location of the power house in relation to the forebay and dam is shown in Fig. 8. The building stands at an angle of 42 degrees with the face of the main dam.[1] It comprises a screen and gatehouse, generating and transformer room. At one end is a chute for ice and other floating material which may collect in the forebay. The whole building is built of concrete. The intake conduit for one main unit is comprised of three openings, 6 feet wide and 16 feet high. Eight feet back from the gates, they merge into one, which is 15 feet wide and for a short distance 13 feet high, and expanding, as the conduit forms the turbine chamber, to a height of 33 feet. There are two draft tubes, one leading from each wheel of the unit, and are separated by a vertical wall; the discharge outlet into the tailrace of each unit is composed of two passages, each 13 feet wide and 15 feet high. This arrangement of the draft tubes, since they are constructed of solid concrete, necessitated very complicated form work, especially as it was necessary to have easily curving surfaces, which would offer little or no resistance to the flow of water. The gates closing the intake conduits are 16 feet high and 6 feet wide, and are raised and lowered by a 15-ton crane. To facilitate the operation of the gates, they are provided with auxiliary gates which are operated by the crane. In front of the gates are screens, which are built up in panels, 10 feet wide, 11 feet high, and 4 tiers to each unit. They are handled by the overhead crane. The draft tubes are provided with grooves for stop-logs.

The Niagara Falls power plants are medium head plants, but of an entirely different design from the McCall Ferry Company's plant. Four of these plants have adopted the vertical shaft turbine located in a pit. The arrangements vary somewhat, especially in the tailrace end. Power House No. 1 of the Niagara Falls Power Company, equipped in 1895 with 5000-HP. units, had no draft tubes; in the later plants, both on the American and Canadian sides, the turbines are equipped with draft tubes of different design, as is shown in Figs. 9 and 10. By eliminating the draft tube in the first plant, 700 HP. was lost for each of the ten units.

It will be noticed in Fig. 11, representing the arrangement of the turbines of plant No. 2 of the Niagara Falls Power Company, that the draft tube is divided, and the

[1] *The Engineering Record*, Sept. 21, 1907.

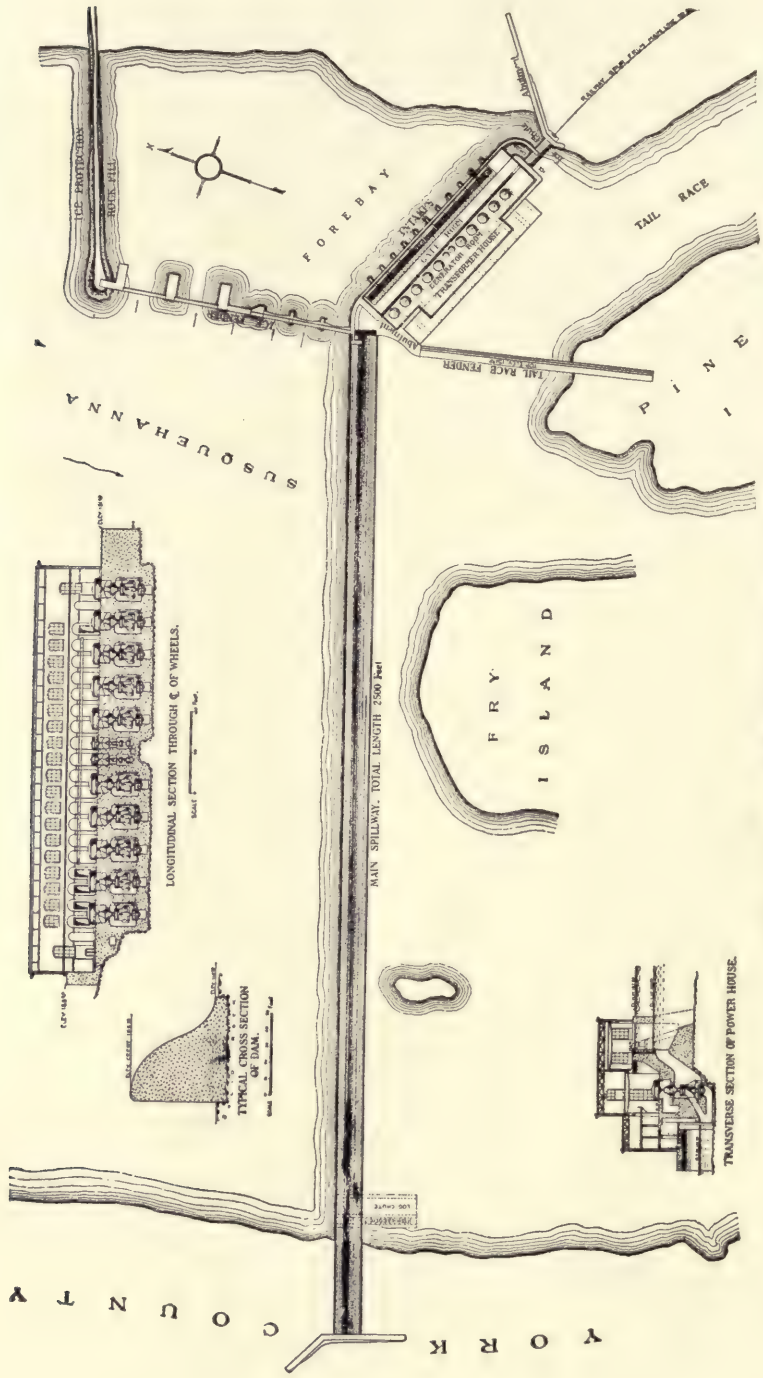


FIG. 8.—McCall Ferry Power Development.

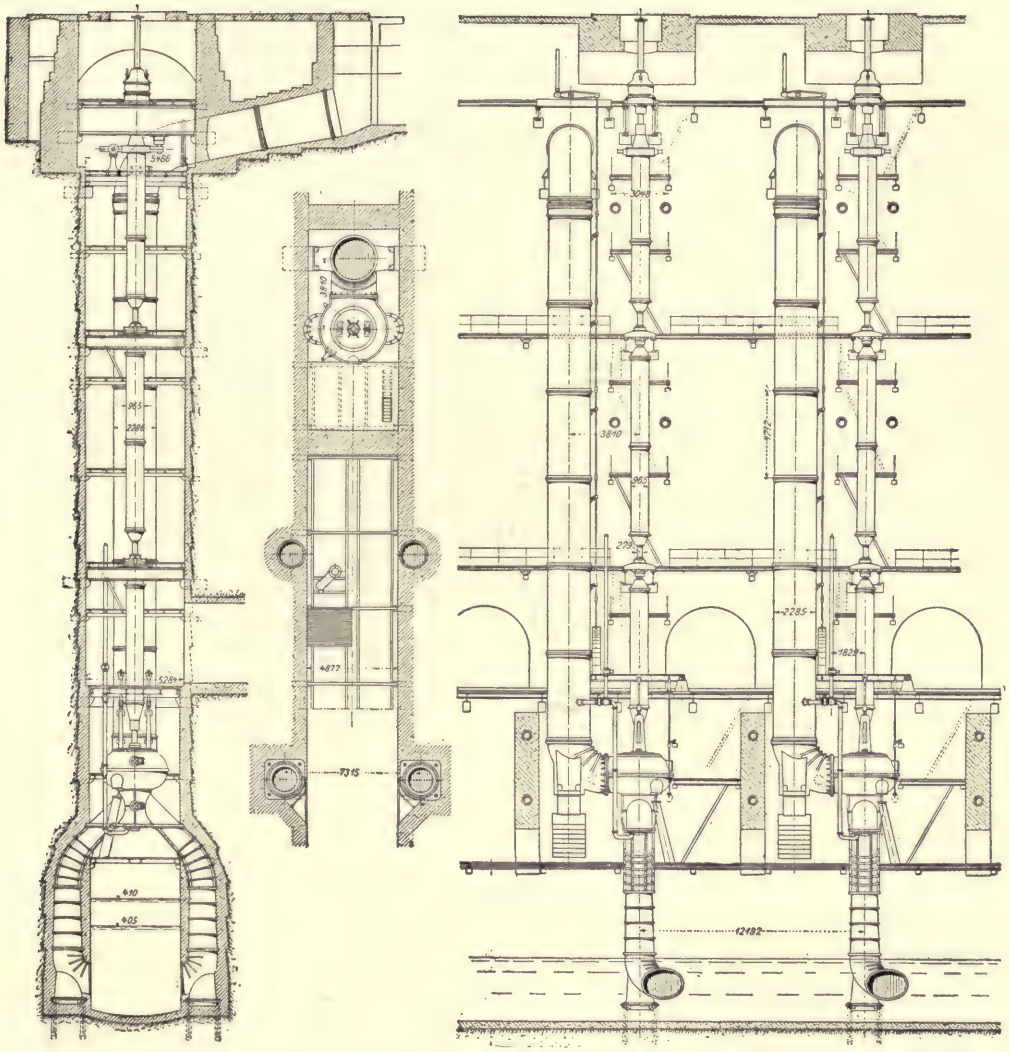


FIG. 9.—Arrangement of Turbines, Niagara Falls Power Company, Plant 2.

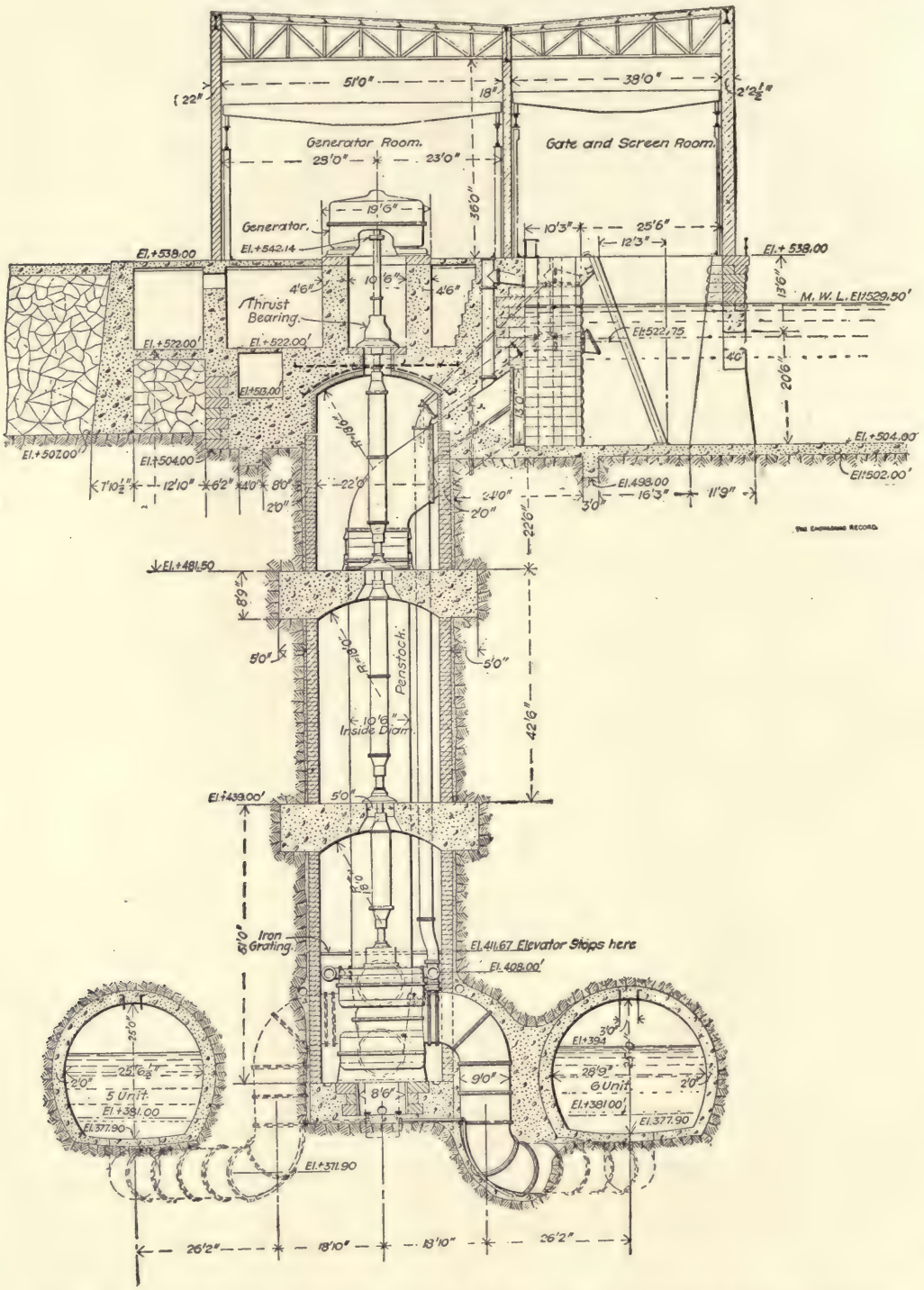


FIG. 10.—Cross Section of Power Plant of the Toronto and Niagara Power Company.

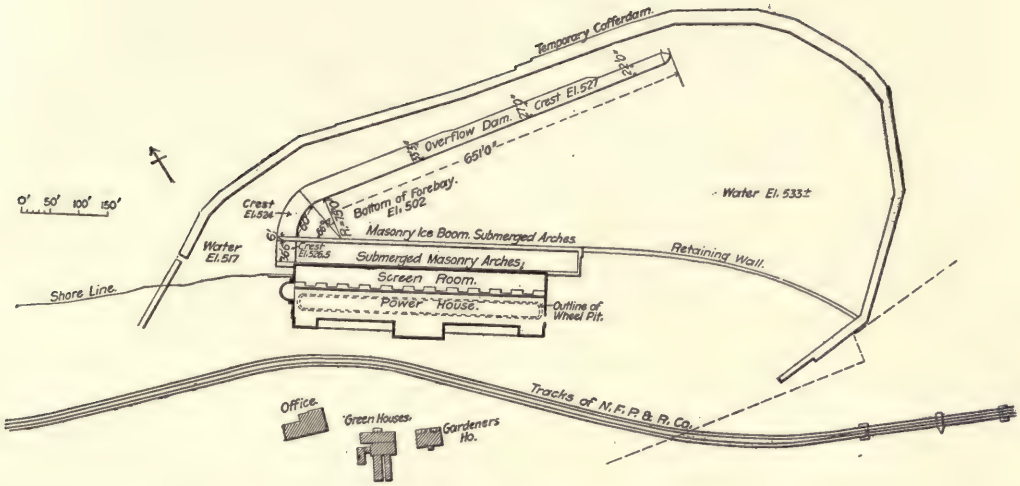


FIG. 11.—Plan of Headworks of the Toronto and Niagara Power Company.

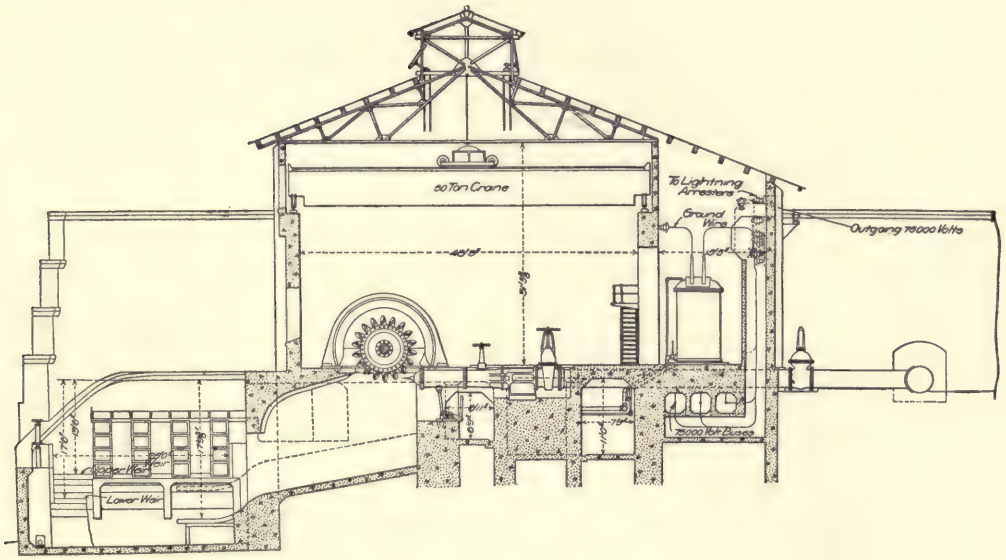


FIG. 12.—Cross Section of Kern River Plant No. 1.

branches run down the sides of the tailrace tunnel. In Fig. 12, showing the arrangement of the turbines of the Toronto and Niagara Power Company, it will be noticed that there are two tailrace tunnels, and the draft tubes discharge into the tailrace from underneath. Half of the turbines discharge into the right-hand tunnel, and half into the left-hand.

The turbines operate, under normal conditions, under a head of 145 feet. As the generators are located some feet above the headrace or forebay, it will be readily seen that long shafts are necessary. These shafts are divided into three sections carried on one adjustable thrust bearing, and guided by two side bearings. In the American plant, the bearings are supported on structural steel galleries, while in the Toronto and Niagara Company, they are supported on heavy concrete arched floors.

The vertical penstocks leading to the turbines are well anchored at the upper and lower end. To allow for expansion, slip joints are provided at the upper end. In digging the turbine pits at Niagara Falls, many difficulties were experienced; some of them have a depth of 175 feet, a width of only 17 to 22 feet, and run the entire length of the power houses, which are 400 to 500 feet long. Much of the work was done in rock of different formation, which was exposed as the work progressed. All the plants are well provided with screens and ice racks, in separate houses. To prevent floating material from entering the forebay and screen rooms, the curtain walls are extended some several feet into the water.

High Head Plants. High head plants usually have a simple arrangement of turbines, but, on the other hand, they have a more complicated arrangement of penstock and regulating devices. It is but natural that high head plants are located away from center of current distribution, therefore a large electrical equipment is connected to the plant. As the ground is cheap in such localities, it would be an unwise policy to crowd the generating room. Ample space must be allowed, particularly for the regulating devices.

One of the most prominent high head plants in the United States is the Kern River Plant No. 1, of the Edison Company, Los Angeles. It utilizes the water of the Kern River, and has a rated capacity of 20,000 K.W. The current at 60,000 volts is transmitted 117 miles to Los Angeles and other towns.

To harness the water of the Kern River, a dam 203 feet long, 20 feet above the river level, was constructed.[1] The water is first led through 19 tunnels, aggregating a length of 42,910 feet; then through timber flumes 1520 feet long, then through a reinforced concrete conduit 503 feet long, where it enters a forebay. From the forebay leads a penstock 1697 feet long, to the power house. Contrary to the usual practice of laying the conduit on the mountain slope, this penstock is run through a tunnel. Throughout the course, there are several horizontal curves and vertical bends, amounting to 40 and 45 degrees. The penstock in the tunnel has a diameter of 7.5 feet, and near the power house the diameter is reduced to 5.25 feet.[2]

[1] The Kern River Power No. 1, by C. W. Whitney. *The Engineering Record*, Aug. 10, 17, 24, 31, 1907.

[2] For details on construction, see chapter on Penstocks.

As seen in the plan (Figs. 12 and 13), the branches from the main penstocks lead beneath the switching room to the impulse wheels. Two Allis-Chalmers impulse wheels drive one 5000-K.W. generator, and are mounted on the overhanging shaft of the generator. Each wheel is 9 feet 8 inches in diameter, and has 18 buckets. The guaranteed output of one pair of wheels is 10,750 H.P. at 150 R.P.M. The nozzle is adjustable, so that the stream can be deflected from the buckets. It is provided at the stationary end with a ball and socket joint heavily bolted down to the concrete foundation. This swiveling head has to take up the full pressure of 375,000 pounds. The regulation of the wheels is effected by a governor, which deflects the jets of the two nozzles. The needles are adjusted by hand, and are usually set so that maximum size of jet which will be sufficient to develop the maximum peak

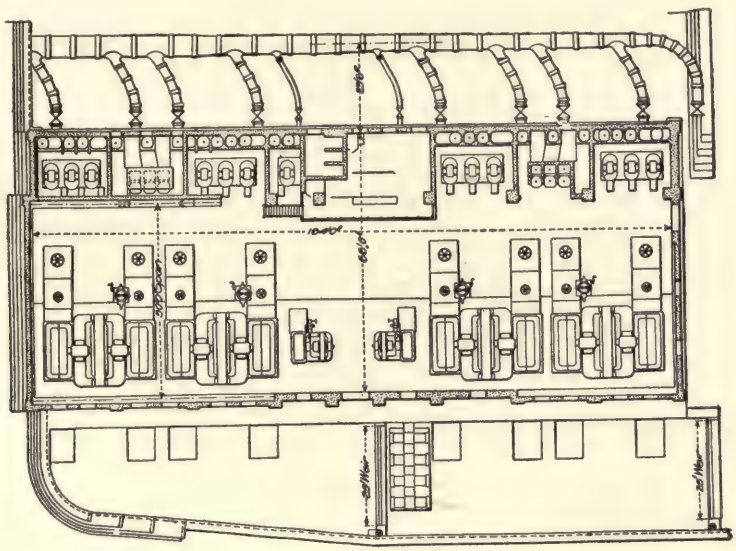


FIG. 13.—Plan of Kern River Plant No. 1.

loads expected for that period of the needle setting; in other words, there is always a maximum amount of water leaving the nozzles. The governor adjusts the deflecting nozzles in such a way that only as much water is directed upon the buckets as is needed for the load for the time being. The balance discharges below the buckets into the tailrace. Each jet has a maximum diameter of $7\frac{3}{8}$ inches and leaves the nozzle tip at a velocity exceeding 225 feet per second. It was necessary to provide means for receiving this tremendous power and deflecting the jet into the tailrace in such a way that its impact would not be detrimental to the structure against which it is directed.

The arrangement designed, consists of a pair of heavy deflector plates by which the jet is diverted. These plates are curved, their design being such as to turn the water through two right angles before it is allowed to pass into the tailrace, thus reducing the force of the water so that it can do no damage. The upper of these plates

consists of a channel, heavily ribbed and bolted to the concrete foundation. The channel at its upper end is slightly more inclined than the deflected jet. Thus, the jet strikes the bottom of the channel at a small angle, and therefore tends to spread and fill the section. The channel gradually widens, and the jet is consequently offered a larger resistance area. The lower part of the channel is curved, and at its end the jet discharges almost perpendicularly downward. The bottom plate is S-shaped, its upper end being flush with the bottom of the wheel pit, the lower end being practically level. The jet strikes the bottom plate almost in the turn of the S and under a small angle. Thus the jet is again forced to spread and follow the base of the bottom plate. The deflectors are lined with movable steel plates wherever the surfaces are exposed to the flow of the deflected jet, and held in position by lag screws. The plates are 7 feet wide, and the lower one projects out into the tailrace 8 feet. The wheel races are lined with steel on both sides, and fitted with steel back plates just back of the nozzle tips, to keep the splash water out of the shaft alley.

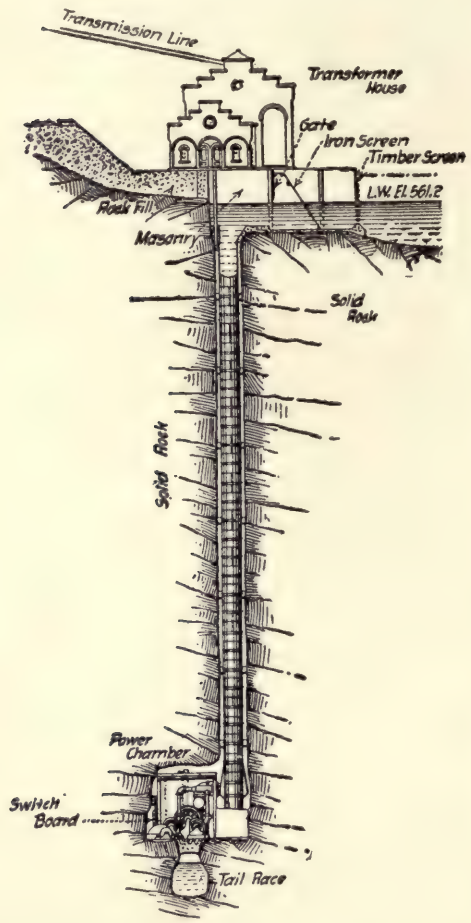


FIG. 14.—Power Plant of Snoqualmie Falls. Power Development.

The tailrace is 29 feet wide and extends the length of the power house. It is fitted with two 25-foot steel plate weirs; the lower weir at the end of the tailrace being 4 feet below the level of the upper, which has its crest 13 feet 6 inches below the line of the nozzles.

The penstock branches enter the power house at the south side, and after passing across the transformer rooms, and before joining the nozzle bases, connect to 28-inch cast-steel gate valves. These valves are of a special design, and are separately operated from the control switchboard by a 1.2-H.P., 120-volt Allis-Chalmers motor. These motors are mounted vertically and operate at 460 R.P.M. It requires $7\frac{1}{2}$ minutes to open or close a valve by means of the motor. All of the gate valves are equipped with 4-inch by-passes. In the machine room of the power house is installed a Dibble reservoir gate equipped with an indicating dial and a registering chart, for measuring the water in the forebay.

A very unique arrangement of a high head power plant layout is that of the Snoqualmie Falls and White River Power Transmission Plant in Washington (see

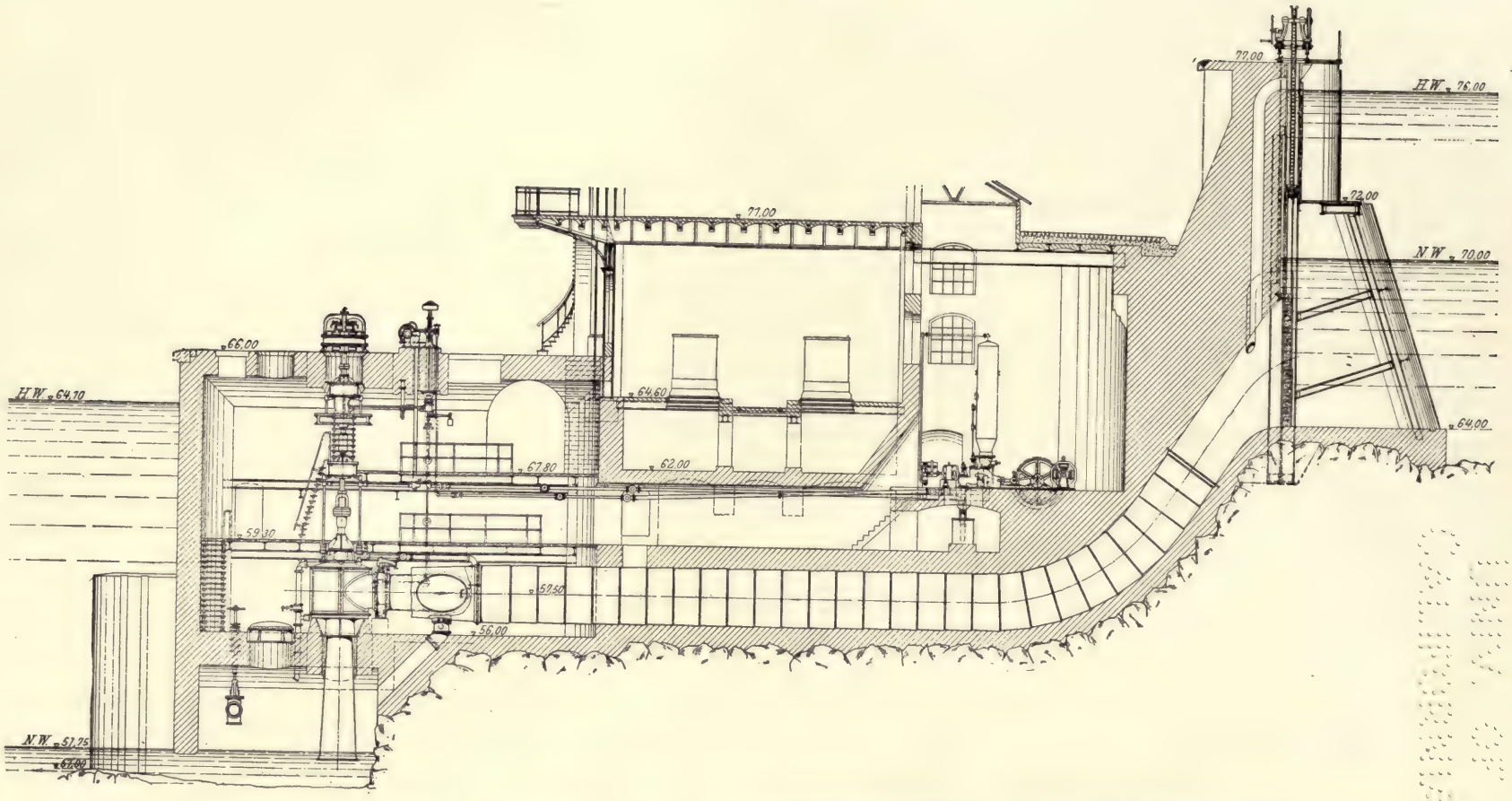


FIG. 15.—Cross Section of Kykkelsrud, Norway. Plant showing Arrangement of Exciter Units and Auxiliaries.

Fig. 14). A shaft of rectangular section, 27 feet long and 10 feet wide, was sunk in the river bed about 300 feet above the Snoqualmie Falls. This shaft reaches a depth of 270 feet, or the level of the river below the falls, and connects with a tunnel 24 feet high and 12 feet wide, having a slope of two feet, utilized as a tailrace.[1] The underground power station begins at the bottom of this shaft and is 30 feet high, 40 feet wide, and about 200 feet long. The tunnel, power house and shaft are lighted by incandescent lamps; the natural draft through the tailrace and up the shaft provides good ventilation. The temperature remains constant at 55° F., and the generating room is perfectly dry.

There are three vertical shafts leading to the power house; one for elevator, and cables conducting the current to the distributing station on the shore; the others for penstocks. The elevator shaft, 10 feet long and 8 feet wide, is lined with steel casing backed with concrete.

The penstock has a diameter of 7.5 feet, and is built of steel plate sections, having a thickness of 0.5 inch on the top and one inch on the bottom. Here it is connected to a horizontal chamber, 10 feet in diameter at the penstock junction and 8 feet in diameter at the opposite end. From this chamber, four 4-foot branches lead to the turbines, which are of the Doble impulse wheel type, having a capacity of 2500 HP., making 300 R.P.M., and connected to 1500-K.W., 1000-volt, 3-phase Westinghouse generators. Each unit is composed of 6 impulse wheels mounted on a common shaft, each wheel having two jets.

EXCAVATION AND FOUNDATION.

Selection of Site. In connection with the head and tail race, and the selection of the site for the power house, the character of the soil must be considered. It frequently happens that forced choice for the site of the power house of a plant is on unsuitable soil. To overcome this difficulty there are two ways: either change the location of the site, or strengthen the soil. It is therefore essential, before drawing up plans of the general arrangement, that accurate information is obtained regarding the bearing power of the soil. This is secured by sinking test holes. If the soil is of an unknown character, test loads must be applied.

Test Holes. Test holes must be sunk in alluvial soil, or made land, to secure accurate knowledge of the underlying strata. Frequently, in the sinking of test holes, rocks are encountered; this indication must not always be taken for strata of rock. To ascertain that rock does not exist, holes, short distances apart, must be sunk, so that an accurate plot of the soil is obtained. These holes are usually 25 to 50 feet apart. When the magnitude of the project does not warrant the use of well or core drilling machines, test holes can be put down by driving iron pipe; a small and large one can be used, the large one acting as a shell for the smaller, to prevent the hole from caving in. A core can be secured by leaving the lower end of the small pipe open, and working without the use of water. An easy method is to force a

[1] *Electrical Review*, June 18, 1904.

A.E.&M.E. UNIV. OF CAL.

stream of water down the small pipe, which, returning to the surface through the large one, brings up specimens of the soil. With a scheme of this kind, holes may be driven 50 feet or more, depending on the character of the soil.

Character of the Soil. When rock is present within moderate depth, the foundation must be carried down to same. The surface of the rock must be leveled and cleaned in order to give a good bearing. The bearing value of rock varies within wide limits, from 10 to 200 tons per square foot and even higher.

A clean sharp sand makes an ideal bearing soil, and is easy to excavate; in addition, it may be utilized in the making of mortar and concrete, which means considerable in saving and expense. Quicksand, either wet or dry, if in thin layers, should be removed entirely; where it is underlaid with a firm strata, it can be confined by means of a concrete coffer dam, and the foundations can then be floated on same. The footing or mat covers the entire area within the coffer dam. In soft or alluvial soil, piling is necessary for heavy foundations. As a general rule, the firmness of the soil increases with the depth; there are exceptions, however. In Chicago, the firm upper layer of soil, from 10 to 20 feet in thickness, is underlaid by a soft clay stratum about 70 feet thick, under which is a stratum of firm clay. Similar conditions have been noticed in different parts of the country. Clay varies greatly in consistency, varying from fluid to hard shale; the latter, when exposed, will disintegrate. It varies greatly according to the opportunity for absorbing or losing water, and because of this, it is very troublesome. To make a good foundation, clay, sand and stone are spread on it, and then well rammed down. The stones should be small enough to permit their being handled by one man.

As a general rule, hydraulic plants are located in rocky, mountainous districts; and as the plants are frequently located on the mountain slope, a simple and efficient way is to blast the rock in steps.

Bearing Power of Soil. For the bearing power of soils, the values in the following table are from Baker's " Treatise on Masonry Construction ":

TABLE I. — SAFE BEARING POWER OF SOILS.

Kind of material.	Safe bearing power in tons per square foot.	
	Minimum.	Maximum.
Rock — the hardest — in thick layers in native bed..	200	.....
Rock, equal to best ashlar masonry.....	25	30
Rock, equal to best brick masonry.....	15	20
Rock, equal to poor brick masonry.....	5	10
Clay, in thick beds, always dry.....	4	6
Clay, in thick beds, moderately dry.....	2	4
Gravel and coarse sand, well cemented.....	8	10
Sand, compact and well cemented.....	4	6
Sand, clean, dry.....	2	4
Quicksand, alluvial soils, etc.....	0.5	1

Weight of Masonry. For the total bearing stress of a foundation on the soil, the weight of the foundation itself must be included. For use in this connection, Table II, taken from the same authority, gives the weights of various types of masonry:

TABLE II. — WEIGHT OF MASONRY.

Kind of masonry.	Weight in pounds per cubic foot.
Brickwork, pressed brick, thin joints	145
Brickwork, ordinary quality	125
Brickwork, soft brick, thick joints	100
Concrete, 1 cement, 3 sand, and 6 broken stone	140
Granite, 6 per cent more than the corresponding limestone	...
Limestone, ashlar, largest blocks and thinnest joints	160
Limestone, ashlar, 12 to 20-inch courses and $\frac{1}{8}$ to $\frac{1}{4}$-inch joints	155
Limestone, squared stone	148
Limestone, rubble, best	142
Limestone, rubble, rough	136
Mortar, 1 Rosendale cement and 2 sand	116
Mortar, common lime, dried	100
Sandstone, 14 per cent less than the corresponding limestone	...

Piling. There are different kinds of piles, such as wooden, sand and concrete. Wooden piles are used in two ways: they are driven down in soft soil to compact it, in which case the bearing power depends entirely upon friction. In other cases, the piles are driven to rock or solid strata, in which case they act as a column. Wooden piles must be cut off below the permanent ground water line to prevent the caps from decay, and on top of wooden piles is spread a concrete cap.

Sand piles are used for strengthening the soil, by driving wooden piles or hollow sheet steel tubes down, then withdrawing them; the hole is then filled with sand. These piles are usually spaced close together, and do not act like wooden piles; the whole soil is made compact.

In the last few years, much use has been made of concrete piles, both plain and reinforced with steel. Two general methods are employed: in one, the piles are molded, then driven; in the other, the mold is driven with a removable core, the concrete being placed after the core has been removed. There are several other schemes of concrete piling, but the principles do not differ from those mentioned. The many advantages of concrete piling are obvious, such as, they cannot decay, and for this reason they can be left as high as desired; and more economical foundations secured, owing to the fact that the ground water line does not signify the point for the cap, as it does with wooden piles. The friction and bearing power is higher than that of wood. In addition, the diameter of a concrete pile can be varied at will, while the diameter of a wooden pile rarely exceeds 14 inches. For this reason fewer concrete piles are necessary for supporting a given load. They are, in a way, downward projections of the monolithic mass of the foundations.

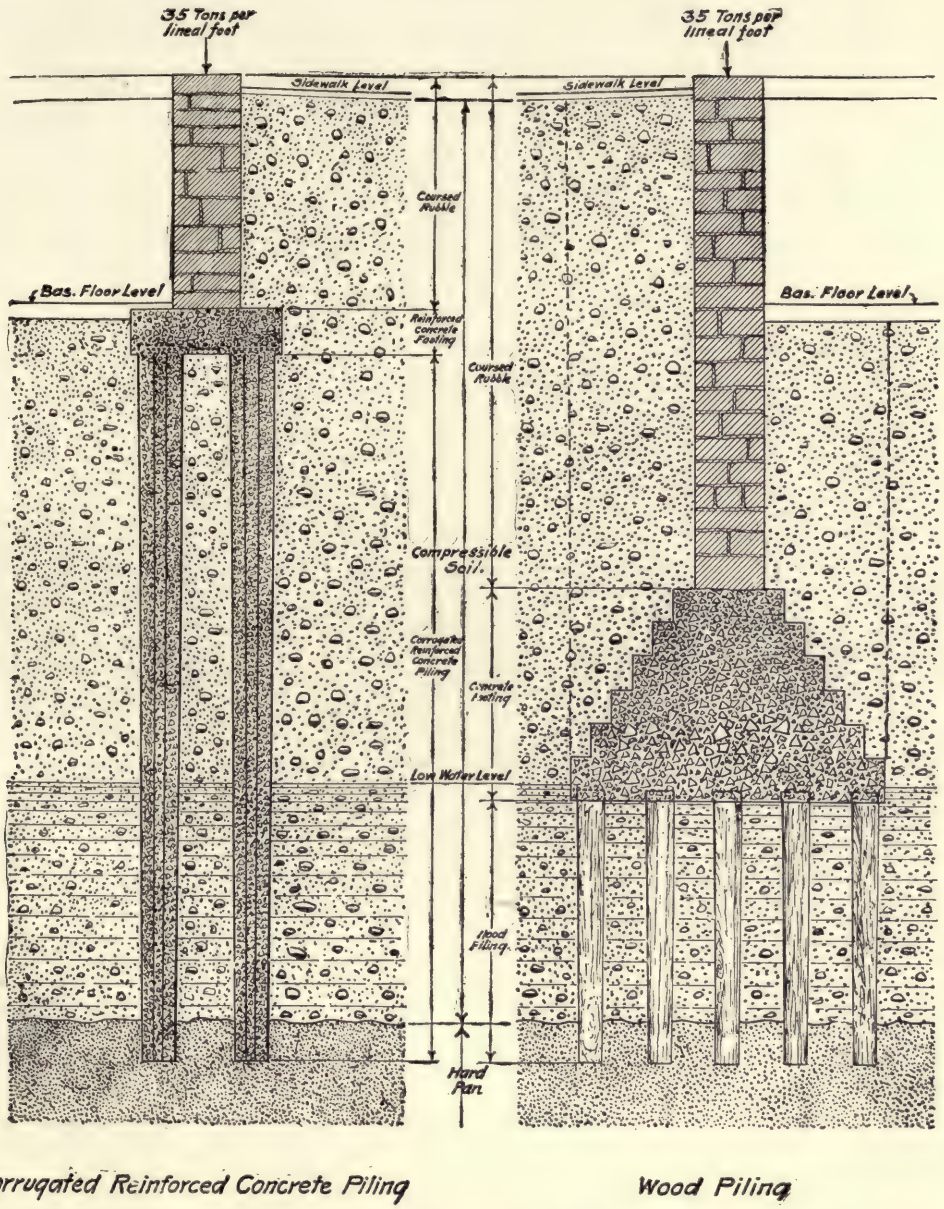


FIG. 16.—Comparison of Foundations using Wooden and Concrete Piles.

Test of Piles. The difference in bearing power between a conical and a cylindrical pile was shown by an experiment, tried on some work at the United States Naval Academy at Annapolis, Md. A Raymond pile core, tapering from 6 inches at the point to 20 inches at the butt, was driven 19 feet, until the penetration, under two blows from a 2100-pound hammer falling 20 feet, was seven-eighths of an inch. A wooden pile $9\frac{1}{2}$ inches at the point and 11 inches at the butt, and of the same

length as the conical pile, had a penetration of $5\frac{5}{16}$ inches under two blows of the same hammer falling 20 feet. A $17\frac{1}{2}$-foot test pile having the same dimensions as the concrete pile above mentioned, and having a penetration of 1 inch under twenty blows of a steam hammer, was loaded with 41 tons. Levels were taken during the loading, and at intervals for one month. At the end of the month the total settlement was 0.007 foot, or three-thirty-seconds inch.

Concrete Mat Construction. Concrete mat construction is frequently used with earth filling, also on soft ground where pile driving has been done. To guard against unequal settlement, it is preferable to extend the mat under the entire building. The thickness of the mat varies with the load to be applied, and may be kept down by reinforcing same, preferably with old rails. The mixture for the concrete in the latter case is 1 : 3 : 6; if a more expensive mixture is desired, use 1 : $2\frac{1}{2}$: 5. When plain concrete slabs are used, rubble concrete may be employed up to a few inches of the floor line.

Foundations. In determining the size of foundations, the weights of the machinery must be secured from the manufacturer. In most cases, the sizes are indicated on the blue prints; this, however, is not sufficient, as one case cannot serve for all; as all depends on the character of the soil. In the case of turbines, the weight of water must be figured in with the weight of the machines.

Foundations must always be made of concrete, 1 : $2\frac{1}{2}$: 5 for the smaller type, and 1 : 3 : 6 for larger foundations. As will be seen in the chapter on buildings, the substructure of an hydraulic plant is usually a monolithic mass of concrete. The forms for the foundation should be so designed that they can be used over and over again, where there are a number of isolated foundations. This is also true in the case of core forms in wheel pits, draft tubes, etc., provided there will be no serious interruption of the work. The forms must not be removed until the concrete is thoroughly set, otherwise the concrete will assume a different shape.

For locating anchor bolts, templates must be constructed. They are made of planking and thoroughly braced with diagonal bracing, otherwise the template will warp out of shape, and throw out the location of the anchor bolts. The drawings should not only contain the elevations of foundations, bolts, etc., but also dimensions to simplify construction of same.

Anchor Bolts. The anchor bolts for machinery are preferably made removable, particularly with large machinery. Under ordinary conditions, they need not project into the foundations more than 18 or 24 inches. They are provided on the bottom end with a cast-iron washer, 6 to 12 inches square. The 6-inch washer is sufficient for bolts 1 to $1\frac{1}{2}$ inches in diameter. They are inclosed, between the washer and foundation (with no grouting), in a pipe, with a diameter about one inch larger than the bolt. The bolts are threaded at both ends to permit adjustment. All bolts, washers and pipes should preferably be of standard size, to minimize expense in draughting department, shop and field.

Grouting. After the machinery has been properly set in place, and anchored down, grout must be poured in to establish a final setting for the bed plate. There must be an allowance in the foundation from one inch to two inches; and even in

small foundations such as for pumps, etc., it must not be less than three-fourths of an inch thick. The grouting itself is a thin, rich mixture of cement mortar with little or no sand, in order to fill up all spaces between the bed plate and foundation and around the anchor bolts.

SUPERSTRUCTURE.

Architectural Features. Rapid progress has been made in the last few years in the design of hydraulic plants and their substations. The designs show a more harmonious agreement between engineer and architect; this, however, varies with the different countries; some lay much stress upon the artistic appearance, while others confine their attention solely to utilitarian objects, disregarding entirely the architectural features. Necessity requires only a building of sufficient support, to shelter and



FIG. 1.—Entrance Hall of Plant No. 2, of the Niagara Falls Power Company.

protect the machinery and those who operate it, and must be of durable construction. An ornamental building will not increase the efficiency of the machinery; it increases the fixed charges. But, at the same time, it is required from an æsthetic point of view, and will, no doubt, have certain effect upon the moral of the operating force, whose efficiency will be increased thereby.

The ultimate aim in the design of an hydraulic plant is, to generate electricity

upon a commercial and economical basis. As a rule, hydraulic plants are located away from centers of population, consequently the architectural features are neglected, as is evidenced by many of the soap-box-like structures in America and England. It seems strange that the hydraulic and electrical engineers of these countries pay little or no attention to the architectural features of buildings.

There are, however, a few examples which show the excellent harmony between the engineer and architect. Some of them are found at Niagara Falls, for example the upper works, or headrace at Dufferin Islands, of the Ontario Power Company, whose power house is located in the Gorge. It might be of interest to give an extract from a report of the park commissioners, when the franchises were granted to the various power companies on the Canadian side of Niagara Falls.

"All of the works and structures connected with the electrical power projects have been designed with the object, not only of doing the least possible injury to scenic conditions, but the commissioners are confident in the belief, that when the several works are completed, the consensus of opinion, by the vastly increased number of visitors that are expected to visit the park, will abundantly sustain them in their contention, that the park as a whole, with its wealth of electrical machinery, will then be of tenfold greater interest to the great majority visiting it."

A building for power-house purposes should not be too ornate, as is frequently found in Europe. Simplicity of design and harmonious agreement with its surroundings are of prime importance. The machinery must be well arranged, sufficient ventilation and an abundance of light provided.

A plant, one of the foremost in America, not only regarding the equipment and capacity, but also from the architectural point of view, both exterior and interior, is that of the Niagara Falls Power Co., Figs. 2 and 3. The superstructure is of rough faced granite blocks with a slate roof. In front of the main structure is the screen house. Both structures are well provided with windows for light and ventilation. The building is tasteful in design and is typical for its purpose, namely, that of a power plant. The interior design of the generating room is in keeping with the exterior, while the entrance hall has been more elaborately treated (see Fig. 1). The electric illumination of the entrance is in perfect harmony with the architectural design. What has been done in main hydraulic plants has been typified in substations, as seen in Fig. 4.

In Europe, the architectural features, from an American point of view, are exaggerated in the extreme. Fig. 5 represents the hydraulic plant of the city of Stuttgart, Germany. The style is that of the fourteenth century, and is much favored in Continental power plant practice. The approach leading from the street to the power house harmonizes with the main structure. This plant is equipped with four 300-HP. hydraulic units, and a small storage battery of 300 ampere-hour capacity. In America this plant is considered small, and in all probability the architectural features would be neglected. It will be observed that much money is spent for architectural purposes, in fancy cornices and off-sets, in the above building. However, it is not necessary to secure pleasing architecture in such a manner; contrast the above plant with that of Obermatt, near the city of Lucerne, Switzerland





FIGS. 2 and 3.—Exterior and Interior of Plant No. 2 of the Niagara Falls Power Company.



FIG. 4.—Substation of Great Northern Power Company, Duluth, Minnesota.



FIG. 5.—Municipal Plant, Stuttgart. Germany.

(Fig. 6). Attention is called to the novel design of the windows. The interior of this power house is given in Fig. 7.

A German plant designed entirely on modern " Secession " style is that of the power plant of the Urfttalsperre at Heimbach, shown in Figs. 8 and 9. The entire design, such as the arrangement and design of the pilasters, roof trusses, windows and switchboards, is patterned on the same line. Special attention is called to the design of the windows and doors, the rear-end wall and side-wing towers. The latter may be taken for ornamental bases for smokestacks. While individual features, such as switchboards, have appeared in Continental practice for years, the design, as a whole, is a bold one in power plant practice.

Material. In the construction of electric plants, it is essential to have the buildings as fireproof as possible. This can be secured by using concrete, brick, terra-cotta, or steel. The material adopted depends greatly upon the locality and on the labor supply.

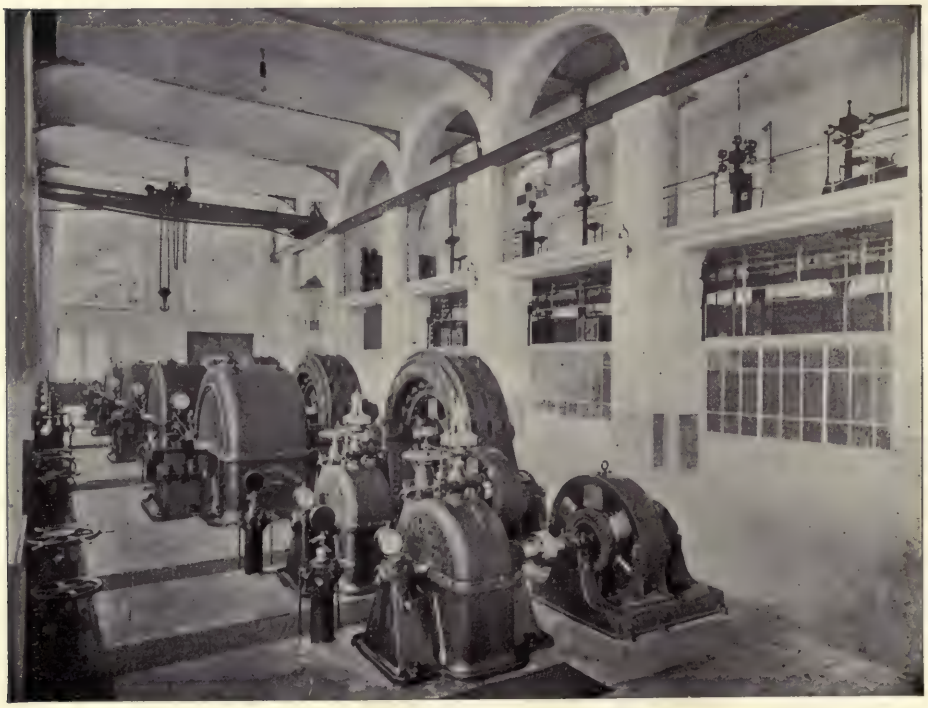
In some countries or sections of countries, skilled labor is easily obtainable; in many places material and skilled labor have to be carried to the site. For buildings in such localities concrete and steel are the best; with a few skilled foremen and pick-up labor, such buildings can be easily erected. This is particularly true in tropical countries where labor is difficult to secure. In countries subject to earthquakes, a framework of steel covered with corrugated iron serves admirably well; the corrugated sheets lapping over each other five inches, and from one and a half to two inches on the side. In some cases painted corrugated sheets are used, owing to their cheapness of cost. The material should preferably be galvanized, in which condition it should not receive a coat of paint until it is exposed to the weather one or two years, and the surface has become slightly oxidized.

Walls. The interior of the generating and switching room should be kept as light as possible. It is advisable to apply a smooth surface of cement plaster, and whitewash same. A more pleasing effect will be secured by facing the walls with enameled tile and a wainscoting of contrasting color. Pilasters may be used to break up the monotony of a smooth surface, and conceal steel columns of the crane runway. The tiling of the walls should preferably be of cream color, while the wainscoting and ornamental panels of olive-green. However, the selection of the latter color is governed by other conditions, particularly that of the floor.

The switching room should be separated from the generating room by a partition wall of fireproof material. Large openings should be left in this wall, particularly in the control switchroom, so that the operators can have an unobstructed view of the generating room; glass partition walls serve the same purpose, and have the advantage of excluding all dust.

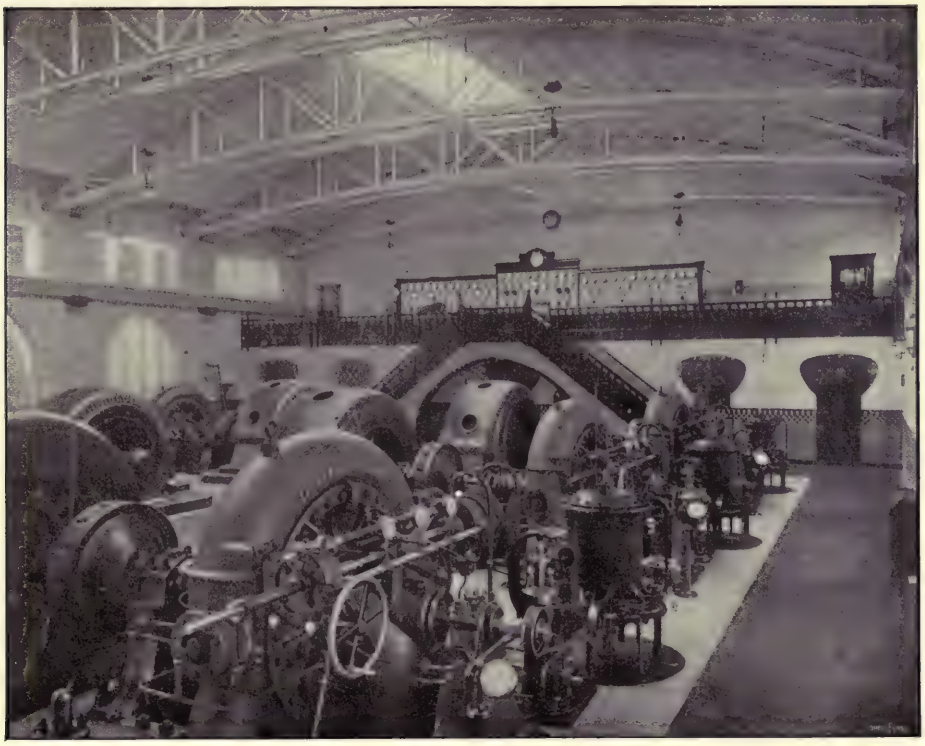
Floors. In the construction of floors, non-combustible material must be employed. As the substructure is, in most cases, built of concrete, it is but natural that the floors should be of concrete; in this case, they must have a granolithic finish of dark color, to render drips of oil inconspicuous. Some authorities dislike concrete floors, for the reason that such floors produce grit by wear, which is stirred up by walking and sweeping, thereby getting into the bearings and other parts of the





FIGS. 6 and 7.—Exterior and Interior of Obermatt Plant, Lucerne, Switzerland.





FIGS. 8 and 9.—Exterior and Interior of Urfttalsperre Plant at Heimbach, Germany.

machinery. Another reason is, that a person on a concrete floor coming in contact with any high-tension wiring, would instantly be killed, while a wooden floor would minimize the risk. The use of wood in power plant construction, and particularly in floors, is obsolete; the principal reason being, that around machinery, there is more or less dripping of oil, which soaks into such a floor and shortly gets into a very inflammable condition. In fact, the whole trouble of some power plant fires has been due to an insignificant blaze of the wooden flooring. Probably, the best floor finish for a generating room is tile or mosaic; being smooth, it is easy to keep clean, and has a very handsome appearance.

Penstock connections and generator leads are frequently laid in trenches, curbed and covered by plates; for the sake of appearance, if possible, they should run lengthwise or transverse to the building. It is poor engineering to have the



FIG. 10.—Municipal Plant, Geneva, Switzerland.

branches of the penstock embedded in the concrete floor, and it is still worse to have flanges of same project above the floor.

Roof. The cheapest non-fireproof roof construction is boards covered with roofing felt, on which is laid a pitch and gravel roof. This type of roof is suitable for slopes ranging from two inches per foot up to 45 degrees, but is preferably confined to the flatter slopes; steep inclines increase the expense materially. Slag and gravel roof is often applied to reinforced concrete slabs or arches. In Continental Europe, pumice stone is occasionally used in concrete for roof purposes; while in America, cinder concrete is often used instead of gravel. Both of these concretes are much lighter than the ordinary gravel concrete.

In constructing a gravel roof, the concrete is first covered with a layer of hot pitch over which is laid the tarred roofing felt, the sheets lapping over each other about half the width of the roll, and each sheet being mopped with pitch as it is laid. Over the entire surface an even layer of pitch is then spread, in which, while still hot, slag or gravel is embedded. Another well-designed roof requires a preliminary preparation in regard to the steelwork in the shape of T-irons laid over the roof purlins. Between these, book tiles are laid, covered with Spanish roll tile. The advantage of the concrete roof construction, and the two latter methods mentioned, is that they are entirely fireproof. Steep inclines are necessary for any tile or metallic roof, and the height should be at least one-third of the span. Where flat roofs are used, surrounded by parapet walls, metal flashing should be provided.

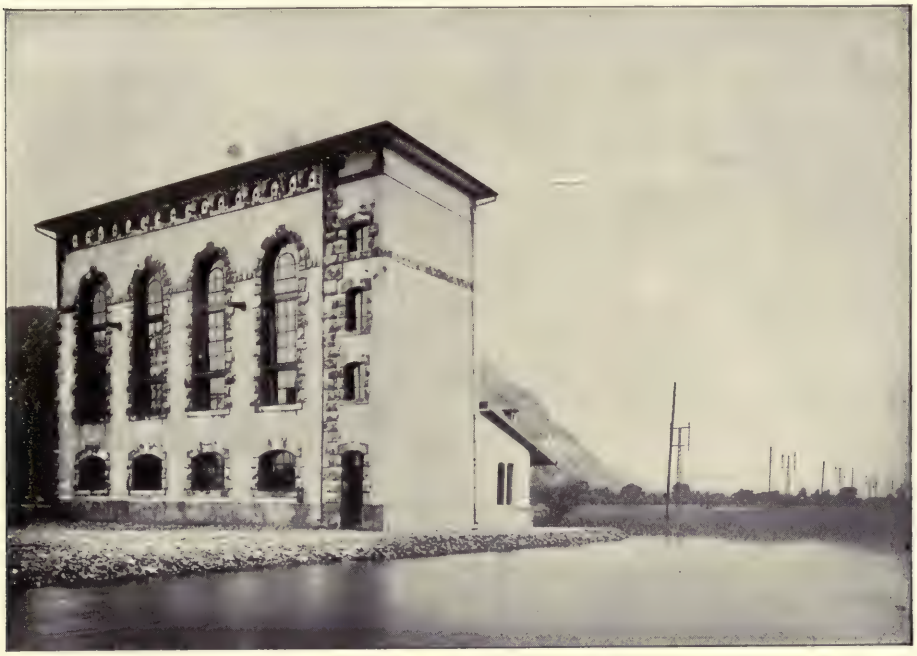


FIG. 11.—Substation, Stansstad, Switzerland.

For tropical countries, the pitch and gravel roofs, so frequently used in the temperate zones, are not suitable, a special material being prepared for use in such climates.

One of the troubles with corrugated iron roofing arises from its making an oven out of the building which it covers, unless an air space is provided to insulate the room directly below the roof from the heat, which may be done by applying sheathing on the bottom chords of the roof trusses. This sheathing reduces the height of the room and increases somewhat the difficulty of properly ventilating it. Another trouble with corrugated iron roofs arises from the condensation of moisture upon their surface, when the roof for any reason becomes cooler than the air. This moisture occasionally causes trouble with electrical machinery.

Leaders. One square inch of leader area must be provided for each 100 to 150 square feet of roof. The leaders must not be smaller than four inches in diameter. In ordinary buildings, galvanized iron leaders are used, while in more pretentious plants, copper of rectangular shape is sometimes employed. All leaders must be provided on their upper ends with removable guards or strainers.

Doors. The door through which material is received should be large enough to admit a railroad car; a door 12 feet wide and 16 feet high will suffice. In some cases, Dutch doors are used, of which the upper half can be used for ventilating purposes, the lower half remaining closed. When it is desirable to open the whole door at once, a folding gate is provided to keep out the curious. Swinging doors are for many reasons inconvenient.

There are on the market various designs of doors for economizing room, such as vertical and horizontal sliding doors, sectional folding and rolling doors. The doors should be ornamental and massive. Oak, well paneled, makes a very handsome door, particularly when trimmed with bronze. In many cases, entire metallic doors of ornamental design are used, as it is desired to avoid the dull appearance of the usual fireproof shutters.

Windows. The generating and switching room must have abundant light, and large windows must be provided. It must be borne in mind, however, that fireproof windows cost from $0.80 to $1.00 per square foot; as walls are always calculated by the builder as solid, the cost for doors and windows is an additional expense. It is common practice to have the windows of ribbed wire glass, because they keep out intense rays of the sun, and do not shatter when broken. It is desirable in some localities, to protect the lower windows of a building with a wire mesh or bars. The window sashes should be metallic or covered with metal.

The windows, together with the crane pilasters, must be symmetrical with regard to the arrangement of turbines. Arched windows are preferable for power plants and are handsome in appearance. If the windows are of large design, care must be exercised to properly panel them to harmonize with the design of the building. Too frequently, the design, as well as the arrangement of windows, spoils the appearance of an otherwise well-designed building.

Stairways and Elevators. Ample stairway provision must be made, because easy access to all points is essential. The stairways should be about 4 feet wide, have easy steps, and be free from turns. Where the floors are more than 12 feet apart, the stairway should be broken by a landing. Stairs should be built of steel framing, with treads of checkered steel, slate, or covered with other anti-slip material. Where elevators are installed, to eliminate the service of an attendant, they must be of the self-starting control type.

Switchboard Gallery. The switchboard galleries must be designed to give plenty of room for all ducts and passages necessary for wiring. In some plants, part of the flooring is made up of slate or soapstone slabs, which can be removed should the necessity arise. The reason for employing this material is, that such stones contain very few metallic elements and are first-class insulators. As a matter of precaution

in other cases, rubber mats are sometimes placed on the floors where attendants have to stand, while operating or making inspections.

The switchboard itself should be of artistic design, harmonizing with the costly instruments. It should be made up of an ornamental iron structure faced with white marble or enameled slate. In central and substations, white marble panels are more in vogue abroad, while the enameled slate is favored in America. All instruments must be well grouped. When instrument pedestals are used, they must be well arranged, and at the same time, convenience of operation must not be sacrificed.

Crane. The crane is not an architectural feature, but even this unpromising subject may yield to proper treatment. It should be designed in a way to conform with the roof trusses. In this connection, the latticed type crane has a better appearance than the unsightly, fish-bellied, box girder, so prominent in use.

Heating. If the plant be located in a temperate latitude, it will be necessary to supply means for heating. The most common means are by steam or hot water. The latter is, however, in many cases, very inconvenient, due to the large amount of radiating surface necessary; there is also the danger of freezing exposed pipes. Steam heating is far better for a large building, being more economically installed and more easily handled. There are two systems of steam heating which may be used that will produce satisfactory results, viz., direct radiating system and hot blast. With the direct radiating system, the heating may be done either by pipe coils or radiators or a combination of both. The coils may be located either on the ceiling or under the windows; the latter method is the more efficient, the necessary radiating surface being about 10 per cent less than that of ceiling coils. A table for calculating the necessary amount of radiating surface to heat a room of given dimensions is given in Table I.

TABLE I. — FACTORS FOR RADIATING SURFACES.

	Radiators.					Coils.				
Outside temperature.	°	°	°	°	°	°	°	°	°	°
Inside temperature.	45	54	63	72	81	45	54	63	72	81
4-inch brick wall	.112	.137	.171	.209	.156	.095	.121	.151	.182	.226
8-inch brick wall	.076	.093	.106	.143	.174	.064	.082	.102	.125	.145
12-inch brick wall	.052	.065	.081	.099	.121	.045	.057	.072	.088	.107
16-inch brick wall	.043	.053	.066	.081	.098	.036	.046	.058	.072	.087
20-inch brick wall	.038	.046	.058	.072	.087	.032	.041	.052	.063	.077
24-inch brick wall	.033	.041	.051	.063	.076	.028	.036	.045	.055	.067
28-inch brick wall	.029	.036	.045	.054	.064	.025	.031	.028	.048	.056
Window, single	.199	.245	.306	.377	.458	.169	.214	.270	.331	.403
Window, double	.094	.105	.144	.178	.215	.079	.102	.127	.156	.190
Skylight, single	.183	.225	.282	.348	.421	.156	.199	.249	.305	.371
Skylight, double	.102	.125	.157	.193	.234	.087	.111	.138	.169	.206
Floor, wood	.014	.018	.021	.027	.032	.012	.015	.018	.023	.028
Ceiling, wood	.018	.021	.027	.033	.041	.015	.019	.024	.029	.035
Floor, fireproof	.020	.026	.032	.039	.047	.018	.022	.029	.035	.042
Ceiling, fireproof	.024	.029	.037	.045	.055	.020	.027	.033	.041	.048
Door	.068	.084	.105	.129	.156	.058	.074	.092	.113	.138
Cubics	.004	.005	.006	.007	.008	.003	.004	.005	.006	.007

The method of using this table is as follows: Calculate the amount of exposed wall and glass surface in square feet, and figure the cubic contents of the room. Multiply these results by the various amounts shown under the headings for the temperature desired; the sum of the results will be the number of square feet of heating surface necessary. It will be noticed that the table calls for an outside temperature of 0° F.; it is general practice to figure this temperature as the minimum.

Hot blast heating is done by blowing air, by means of fans, over coil surface and transmitting the heated air to various points of discharge by means of galvanized iron ducts. There are two methods of doing this, — one by recirculating the air, that is, using the air in the room over and over again. The other method costs more to operate, but insures better ventilation, as it supplies heated outside air.

The style of boiler to be used depends entirely upon the size of the plant; up to 25 HP. a cast-iron sectional boiler will produce good results; up to 100 HP. a horizontal tubular or a locomotive boiler is as good as can be used; anything over this, a water tube boiler will be found most economical. It is advisable to locate the boiler in a separate building, in order to remove any possibility of dust and ashes accumulating on the machines.

For calculating the size of the boiler, 100 square feet of radiating surface to one boiler horsepower (30 pounds of steam per hour) for direct radiation is the accepted practice. For blast coil work, a rough rule is 30 square feet of radiating surface per boiler horsepower. This latter, however, is inaccurate, as there are numerous other conditions, such as shape of heaters, number of air changes per hour, etc., which must be taken into consideration. The steam mains supplying the heating system may be calculated on the following velocities: 5000 to 6000 feet for the main distributing lines; 3000 to 3500 feet for vertical rising lines, and 1200 to 1500 feet for individual branch mains. No branch main should be less than 1-inch pipe. These velocities are for low-pressure steam. The return mains are generally one-third to one-half the size of the supply mains. Careful provision must be made that all piping pitches in the direction of the flow of steam; this pitch must be at least three-fourths inch in every 10 feet.

It is important to cover all supply and return mains with a good non-conductor, not only for economy's sake, but also to minimize the fall in pressure in the steam main which often produces snapping and cracking in the pipe.

Ventilation. For ventilating generating room, louvres with swinging windows should be avoided in the roof, above or near current-carrying apparatus such as generators, motors or switchboards. The windows in the wall on the switchboard side must be fastened, no provision being made to open same, or else a locking system provided. This precaution must be taken to prevent short-circuits caused by rain and dust particles, blown in from the outside.

Where air blast transformers and storage batteries are installed, forced draft must be used; the discharge gases of the latter must be carried through special ducts up through the roof.

A.E.&M.E
UNIV. OF CAL

Lighting. To provide for an emergency, in case of a complete shut down, both generating and switching room must be provided with a multiple system of wiring. This is essential, for instance, in the alternating current plant with motor-driven exciters; a complete shut-down would seriously handicap the locating of the trouble. In modern plants, the switch gear is operated by motors, supplied by a storage battery which may furnish light also. As much as possible, wires must be concealed and run in ducts of approved design.

Lavatories. For sanitary reasons, well-equipped lavatories must be installed in all plants. The plumbing must be of good substantial material, enameled basins, bowls or sinks. Bowls are preferable to sinks; bath and toilet floors should be tiled; the partitions of white enameled slate, or, if a more expensive construction is desired, of marble. The advantage of white finish is, that it enforces cleanliness by making dirt conspicuous. The drain must run to avoid all ducts and wiring, and be properly provided with traps and vent pipes; the latter must extend above the roof.

Preferably at the side of lavatories, lockers should be installed to enable the men to change their clothes and clean up. The lockers must be large enough to contain a complete change of clothing, permitting a man in winter to hang up an overcoat. Sufficient room must be given in the aisles to allow the men to make necessary changes.

Conclusions. Many have biased opinions, that by the erection of power plants for the utilization of water power, the scenery of the country will be destroyed. It is an entirely mistaken idea. It is only a matter of ability, on the part of the engineer and architect, to design a plant to harmonize with the surroundings. In fact, plants have been installed, greatly enhancing the beauty of the scenery of the country. To bear out this statement, illustrations are given in Figs. 12 and 13. The latter is the head race of the 15,000-HP. plant utilizing the water of the Sill, near Innsbruck, Tyrol. The valley without the canal, spillway, and building for attendants, would undoubtedly be monotonous, particularly in the mountainous country. Considering Fig. 14, the power plant at Tivoli on the Tiber, it is perhaps the most picturesque power plant ever designed. The building itself with its few arched openings is simple; the headrace is designed after the style of the old Roman aqueducts, and carries more water than the power plant needs. Without question, the scenic value of the country has been increased. This is more remarkable, because the plant was not erected for the immediate locality, but to serve the city of Rome.

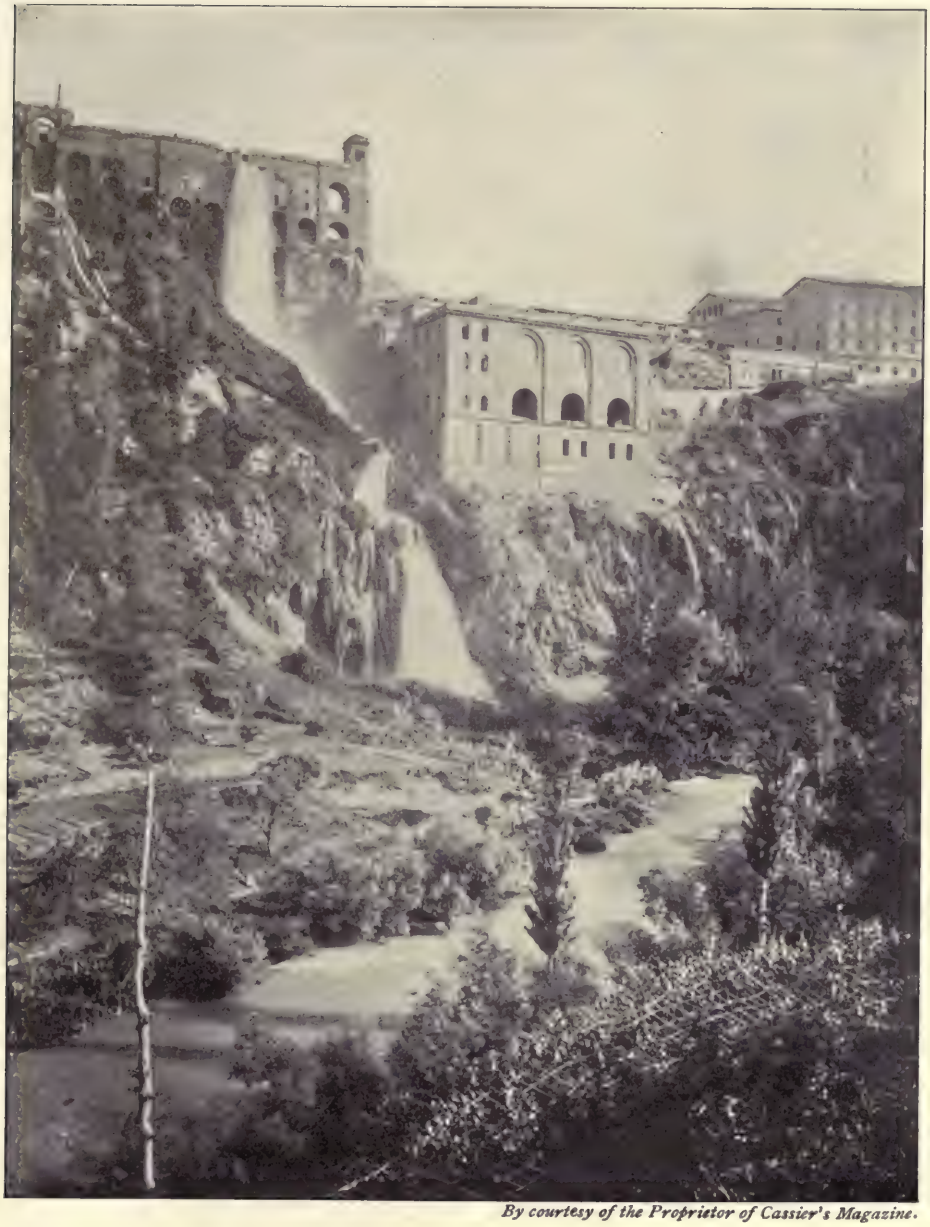
It cannot be expected that all plants should be architecturally treated in the same manner as some of the above cited. However, it must always be remembered that a pleasing appearance can be secured at little or no additional expense. In fact, many prominent plants which are masterpieces of ugliness, have cost more per unit capacity than those which are noted for their fine appearance; a proper knowledge of architecture being requisite to secure good results.



FIG. 12.—Bird's-Eye View of "Sillwerke," Tyrol.



FIG. 13.—Headrace of the "Sillwerke," Tyrol.

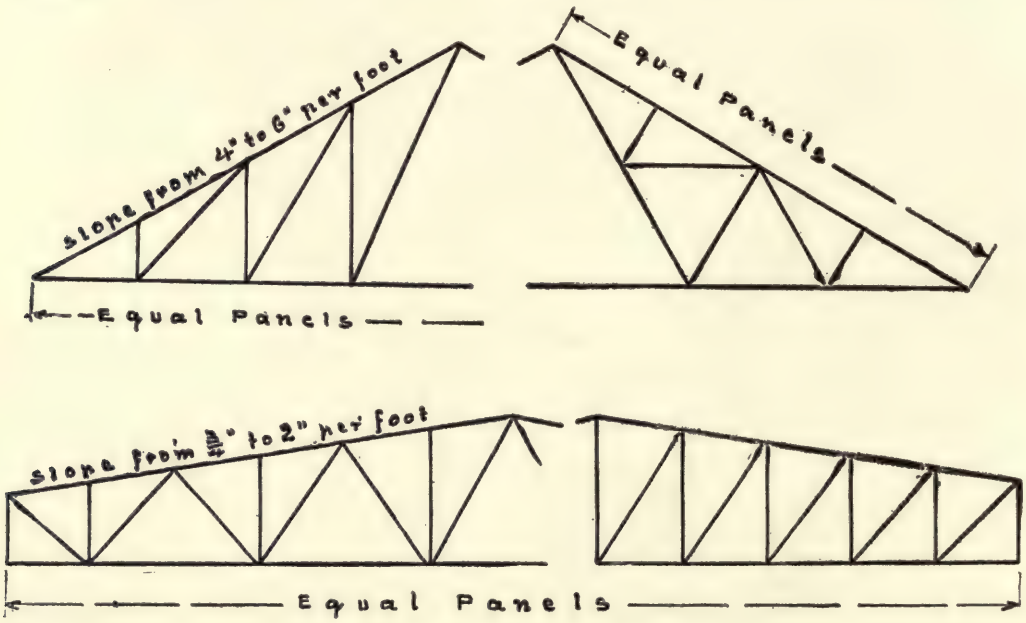


By courtesy of the Proprietor of Cassier's Magazine.

FIG. 14.—Tivoli Plant, Rome, Italy.

STRUCTURAL STEEL.

Roof Trusses. As it is essential that structures be fireproof, first of all, structural steel roof trusses are required. In small plants, the roof trusses are preferably carried on the side walls; while in large plants, the trusses are carried on columns, which support also the crane runway. The outline of the roof trusses depends upon the kind of roof to be supported and the pitch, which depends also upon architectural conditions. When slate and shingles are the only roofing materials available, steep slopes are necessary, in order to cause the water to run off rapidly, and prevent its working up under the roof and causing leaks. With modern methods of waterproofing, a slope of 2 inches per foot is sufficient to supply the requisite drainage. Such roofs have many advantages: they require less material than those of steeper pitch; also, they are easier to build, and the waterproofing is readily applied. Steeper roofs, however, are often used, owing to the fact that they are considered more economical in steel, but this advantage is more than offset by applying the roofing.



FIGS. 1 to 4.—Typical Roof Trusses.

The accompanying sketches, Figs. 1 to 4, illustrate some of the usual forms employed in roof construction. An inspection of the various cross sections of plants given in different parts of this volume, show a number of other forms of roof trusses in actual use, some of which are more or less ornamental. In the design of roof trusses, it is necessary to know the span and the load as well as the spacing of the trusses. In power plant work, the location of columns is largely determined by the equipment. For the sake of rigidity, the trusses must be directly connected to the columns; it will therefore be seen that the span and distance between trusses is

fixed, and that this distance may or may not permit the most economical design of truss. The loading depends upon the locality of the plant, and the style of roof to be used. In New York City, the live load of a roof having a pitch less than 20 per cent, is 50 pounds per square foot, and for a pitch exceeding 20 per cent, is 30 pounds per square foot. This live load (snow and wind) is the vertical component on the projected area. In localities subject to severe wind storms, the roofs must be properly anchored, particularly when they rest on walls. The top chords of the trusses are tied together by purlins, which support the roof; on deep trusses, the lower chords have longitudinal bracing. In addition, at the end panels, and in long buildings at intermediate panels, angles or chords are used for diagonal bracing in the plane of the upper and lower chords. An overhead crane, operated by power or hand, is essential in the generating room, also in the transformer room of larger power houses. In brick buildings, the crane runways may be supported on pilasters of the wall designed for this purpose. This type of construction is adopted only in small and comparatively low buildings, or in localities where masonry is cheaper than structural steel.

In localities where building materials are expensive, it is better to erect a corrugated sheet steel iron frame structure. This is particularly true in tropical countries where the labor and building materials have to be imported. For this type of building, galvanized corrugated iron is used, Nos. 18 and 24 gauge, and for the roof, Nos. 20 to 26 (United States Standard). The siding is in all cases two gauges lighter than that of the roofing. Black or painted sheets are occasionally used, but as they are not so durable as the galvanized sheets, they cannot be recommended. The best grade of this material is called "Muck Bar" corrugated sheeting, and is much more durable when exposed to moist air. A corrugated iron building can hardly be classified as a permanent structure, and cannot be recommended for modern power plant practice. There are several methods in use for the design of structural steel buildings. In one, the frame is self-supporting, and the light curtain walls are partly supported by the steelwork; while on the other hand, the structural steel, as well as the walls, is entirely self-supporting.

Columns. The building columns should be of the open type as much as possible (see Figs. 5 to 7). The use of box girders and columns should be avoided, because



FIGS. 5 to 7.—Typical Columns.

they are usually built up of channels, I-beams and plates, and are more apt to corrode inside than out, as they cannot be painted inside; to overcome corrosion, they may be filled with concrete.

Column Bases. The columns are preferably designed with a base of sufficient area to permit of their being set directly upon the foundation, but cast-iron base

plates are sometimes interposed at this point, as they can be leveled up before the column is erected. Grillages are undesirable, but cannot be avoided with heavy column loads.

Floors. In hydraulic plants, little use is made of floorbeams as far as the generating room is concerned; the whole substructure is made of solid concrete. However, in the design of the floors in the switching and transformer rooms, considerable structural steel is used. In many cases, the floors are subjected to concentrated local loads at various points, which require special treatment. In other cases a railroad spur extends into the building, to facilitate the handling of heavy material by an overhead crane. The load for which the floors must be designed, is the weight of the heaviest pieces of machinery placed on them. It must be borne in mind, that

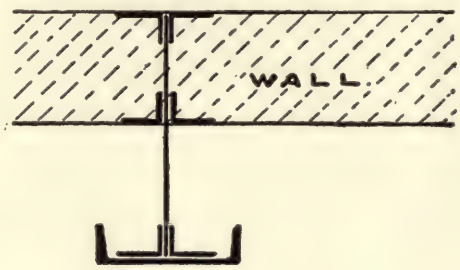


FIG. 8.—Crane Column.

during construction, large quantities of material are apt to be piled on the floor, consequently precautions must be taken. As the weights of the various pieces of machinery, such as generators, transformers, etc., change so very greatly with their functions, this data must be obtained from the manufacturer.

In countries where only the lowest grade of labor can be obtained, and conditions do not warrant the sending of an erecting force, but only a foreman, the steel sections may be bolted together and filled instead of being riveted. Experience has shown in some cases, that abutting pieces had to be provided with dowel pins to facilitate erection.

The use of floor arches causes a lateral thrust against all of the beams composing the floor system; for this reason it is necessary to introduce tie rods, suitably spaced, to take care of this stress. These tie rods should always be placed high enough so that they will be hidden by the floor arches, as this adds greatly to the appearance of the ceilings. In some plants this detail has been neglected, and the result, to say the least, is unsightly. Another small point, is the provision of curb angles around all hatches and other openings in the floors; these angles should project from 2 to 3 inches above the finished floor level, their purpose being, to prevent wash water, sweepings, etc., going down to the floor below. The value of these curbs is more apparent in those cases where machinery is located on the lower floors, or under the galleries, which would be liable to damage from anything dropping on to them.

Expansion Joints. In very long buildings, the expansion due to changes of temperature must be taken care of during erection, but such precautions are not required

in small buildings. In buildings under 300 feet in length, temperature variations do not cause much trouble, and no special precautions are required to care for them. In some cases, where expansion joints are used, it is specified, that after the building has been walled in, the joints shall be blocked with lead to prevent any motion of the steelwork cracking the concrete flooring, etc. The necessity of these joints is only during the erection period, when longitudinal expansion is very apt to make it difficult to erect portions of the steelwork.

Fiber Stresses. Steel structures are proportioned, in regard to the sections used, by a limit set on the fiber stress in tension, which is reduced, for compression members, usually by Gordon's formula. In many localities, the limiting unit stresses are specified in the building laws, these in some cases being limited in their application, to some particular city; in other cases, they apply to a state or nation; the legal requirements differ greatly in different localities, hence it is advisable to investigate the subject unless the requirements are well known. In practice, the fiber or unit stresses for steel in tension vary from 13,500 to 20,000 pounds per square inch; for most of the important structures, the working stresses have been kept between 15,000 and 16,000 pounds per square inch.

Character of Steel. A large portion of the structural steel manufactured in the United States is made under the "Manufacturers' Standard Specifications" as revised to Feb. 6, 1903, which permit the use of either open-hearth (Siemens-Martin) or Bessemer steel (the Bessemer steel produced in the United States is made by the acid process, no basic Bessemer steel being produced). The practice of specifying open-hearth steel exclusively, for most structures, is growing, owing to the fact that it is more homogeneous in its physical properties. Bessemer steel, on the contrary, is liable to fail in service, in an irregular and inexplicable manner, and for this reason it is not desirable for structural work.

All steel made by the open-hearth process must be of uniform quality, tough and ductile. The phosphorus must not exceed 0.08 per cent. Rivet steel must have an ultimate tensile strength of from 45,000 to 55,000 pounds per square inch. Structural steel must have an ultimate tensile strength of from 55,000 to 65,000 pounds per square inch. The elastic limit must not be less than one-half of the ultimate tensile strength.

The percentage of elongation must be equal to:

$$\frac{1{,}400{,}000}{\text{Ultimate strength in pounds per square inch}}.$$

Rivet steel, before or after heating to a light yellow heat and quenching in cold water, must stand bending 180 degrees flat on itself, without signs of fracture. Structural steel, before or after heating to a light cherry-red heat and quenching in cold water, must stand bending 180 degrees, to a curve whose diameter does not exceed the thickness of the sample, without signs of fracture. The finished bar plate and shapes must be free from all cracks, flaws, seams, blisters and all other defects; it must have a smooth surface and be well straightened at the mill before shipment.

The tensile strength, limit of elasticity and ductility must be determined from

standard test pieces, of at least one-half square inch sectional area, cut from the finished material; two opposite sides of the test piece must be the rolled surface, the other two opposite surfaces to be milled or planed parallel; rivet rounds, however, must be tested of the full size, as rolled. All test pieces must show a fracture of a uniform fine-grained, silky appearance, of a bluish gray or "dove" color, and must be entirely free from granular, brilliant and black specks of a fiery luster. Every finished piece must be clearly stamped with the melt numbers.

The inspection of the steel, to insure its compliance with the specifications, necessarily takes place at the mill. It is common to introduce a clause in the specifications, by which if any material accepted at the mill, when under the punches or shears, shows that it is not of uniform quality, it may be rejected at the shops. In some cases a drifting test is called for, by which a hole punched in a plate or piece, the thickness of the material in some cases being specified, can be drifted to a larger diameter, without cracking either the edges of the hole or the external edge of the piece, the increase in the diameter of the hole ranging from one-third to one-half the original. The distance from the center of the hole to the edge of the piece may be specified.

Workmanship. The following, in reference to workmanship, is based on the standard practice of some of the leading concerns. All material must be punched one-sixteenth of an inch larger than the nominal size of the rivets, except that material five-eighths of an inch thick and over, must be drilled or subpunched and reamed one-eighth of an inch larger in diameter, so as to remove all sheared or burred edges. (In some cases subpunching is insisted upon when more than one cover plate is used on columns or girders, in which case the reaming must be done after the parts are assembled and clamped together.)

All work must match so accurately, that after assembling, the rivets can be entered without drifting.

Whenever possible, all rivets should be machine driven by direct acting machines, operated by compressed air, steam or hydraulic pressure, which should be capable of retaining the applied pressure after the upsetting has been completed. Field riveting should be done, preferably, by long-stroke pneumatic riveters. Hand riveting should not be permitted for rivets over seven-eighths of an inch in diameter.

The details must be designed to avoid riveting in difficult or inaccessible places. No bolts should be used, except by permission; they must be turned to a driving fit, and the bolt holes drilled and reamed after the parts are assembled and clamped together. In many cases, however, the roof purlins are bolted with ordinary black bolts, all other connections being riveted. The abutting surfaces of compression members must be truly faced to an even bearing. (In some cases this clause is extended to cover the tops of column bed plates in a specific manner, and in some rare instances it is specified that the abutting ends of tension members must be faced.)

All rivets, when heated and ready for driving, must be clean. When driven, they must completely fill the hole and have round concentric heads of uniform size, thoroughly pinching the connected pieces.

Inspection. All facilities for the inspection, testing of material and workmanship, must be furnished by the contractor to duly appointed inspectors, but the inspection for the raw materials must be made at the mills or foundries where the steel is rolled or the castings made. The inspectors must be allowed free access to all portions of the plant in which any portion of the material is made.

Painting. In regard to painting, there are a number of differing requirements, such as, raw and boiled linseed oil, iron ore or iron oxide paint, red lead paint, graphite paint, etc., and there are a number of proprietary mixtures on the market of more or less value. The proportion of the materials to be used in preparing the paint, and the kind of brushes to be used in applying it, are sometimes enumerated. The proportion of red lead used, varies from 16 to 40 pounds per gallon of oil, depending upon the quality; a paint containing 25 pounds of red lead per gallon of oil makes a very satisfactory coating for steel, the following formula being a very good mixture:

25 pounds of pure red lead,
1 gallon of pure raw linseed oil,
$\frac{1}{8}$ pint of japan, free from benzine.

Iron ore or oxide paints possess the merit of being cheap, and for this reason are much used. They are not reliable, and should be avoided in good practice. Boiled linseed oil without a pigment makes a good coating for iron or steel. The pigment addition acts as a filler for the pores in the oil, and retards its drying or oxidization, and for this reason driers are used, japan being one of the best materials for this purpose, provided it is free from benzine. The use of benzine, sometimes called gasolene or naphtha, must not be permitted in any paint which is to be applied to ironwork, for the rapid evaporation of the benzine will cool the material to a point where the surface to be painted will be covered with a dew or moisture. At least 48 hours must elapse between the application of each coat of paint. Painting should not be permitted during freezing or wet weather. The writer would be inclined to specify that painting should only be permitted on clear days, when the temperature was above 40° F. In riveted work, all surfaces coming in contact must be painted, before assembling, with one coat of paint on each surface. Occasionally it is specified that all portions of the work to be embedded in concrete or brickwork must receive one or two coats of asphaltum varnish. All the work must receive at least one coat of paint before it is shipped; and after erection, all places where the paint has been rubbed off, and the heads of the field rivets, must be painted, after which the entire structure must receive two coats of paint.

There is very little agreement in regard to the best coating for any particular case, probably because so much depends upon the preparation of the surface to receive the paint, the care with which it is applied, and the exposure conditions.

All dust and loose scale must be removed before the paint is applied, and the painter should follow immediately after the cleaner.

Prevention of Electrolysis. At various times it has been proposed to insulate the steel frames of power houses, with the idea of preventing electrolytic action. The

complete insulation of the frame is impractical, owing to the fact that a number of pipes must be supported by hangers bolted, or otherwise secured, to the framing; some of these pipes being in connection, electrically, with the ground water, an attempt at insulation is extremely liable to localize the electrolytic action at a few points, which would be worse than the troubles arising from the entire omission of insulation.

At the site of erection, or adjacent thereto, it is usually necessary to store portions of the structural material, after it is unloaded and until it is required for erection. This material must be laid on skids, so that it does not come in contact with the ground and must be kept clean.

CHAPTER VI.

MECHANICAL EQUIPMENT.

TURBINES.

Classification. As regards the behavior of the water, turbines may be divided into two general types, the reaction and impulse. In the former, the flow of water must be continuous in all parts of the turbine, that is, the entire runner is under water; in the impulse type, the water impinges on parts of the wheel, and in nearly all cases the atmospheric air has free access to the remainder of the runner. Turbines may be further divided as regards their construction, into radial, axial or parallel flow and combined or mixed flow. In the radial type, the water passes through the wheel, either inward or outward at right angles to the axis of rotation. In the axial turbine, the general direction is parallel to the axis of rotation. In the mixed flow turbine, the water enters radially and discharges axially, or vice versa. The different types of reaction turbines are commonly known by the names of their inventors, as the Fourneyron, which is a radial outward flow; the Francis, a radial inward flow; and the Jonval, a parallel flow. A combination of the Jonval and Francis is known as the American type, and is to-day the most common one used in America, where it had its origin. Of the impulse type, the Girad and the Zuppinger in Europe and the Pelton in America are the most familiar. In regard to the origin of the impulse wheel, it might be of interest to state, that Zuppinger in 1846 installed his first tangential wheel at Weiler's Mills near Friedrichshafen on Lake Constance.[1] The same engineer, who was at the time connected with the Escher Wyss Company, built in 1868–69 for the Haemmerle Cotton Mill in Dornbirn, Voral Mountains, Germany, a tangential turbine of 220 H.P., making 300 R.P.M. under a head of 550 feet.[2] This tangential impulse wheel was 5 feet in diameter, 30 inches wide, and mounted upon a vertical shaft and provided with two diametrically opposite jets or nozzles; it was designed for a water supply varying from one to six cubic feet per second, and as the designer up to that time had not constructed wheels to operate with over 380 feet head, he thought it advisable not to give a guarantee of more than 65 per cent. However, during actual operation, with a water consumption of 1.5 to 2 cubic feet per second, the efficiency was 70 to 75 per cent; with a water consumption of about 5 cubic feet per second, was 65 to 70 per cent.

Turbines are also classified as follows:

I. Low head — up to 30 feet.
II. Medium head — from 30 to 200 feet.
III. High head — above 200 feet.

[1] Letter by Prof. Escher, Zeitschrift des Vereines deutscher Ingenieure, Feb. 18, 1905.
[2] Grosse moderne Turbinenanlagen. L. Zodel, Schweitzerische-Bauzeitung, June 13, 1908.

This classification is not strictly adhered to, as many manufacturers and plant designers are ignorant of the fact that a low head turbine is less efficient when applied to a high head, and vice versa. Reputable manufacturers with competent engineering staffs will advise the use of such a turbine as is most suitable for the condition at hand. Slight variations of the above are sometimes made, when other conditions favor the same. A rigid classification by European engineers is as follows: [1]

Low head turbine, up to about 10 feet.

(With open flumes, vertical shafts with bevel gearing. When above ground water, horizontal shaft with belt or rope drive.)

First intermediate head turbine, from 10 feet to about 35 feet. (Open penstock, which is possible up to 35 feet; vertical, or when advisable, horizontal shaft.)

Second intermediate head turbine, from 35 to about 165 feet. (Closed penstock, spiral casing, horizontal shaft. Of course for special conditions vertical shafts may be used.)

High head turbine, above 165 feet. (Closed penstock, spiral casing, horizontal shaft, as long as reaction wheels are considered; otherwise, impulse wheels with horizontal or vertical shaft.)

As this close classification is seldom applied to American practice, a more liberal classification must be made.

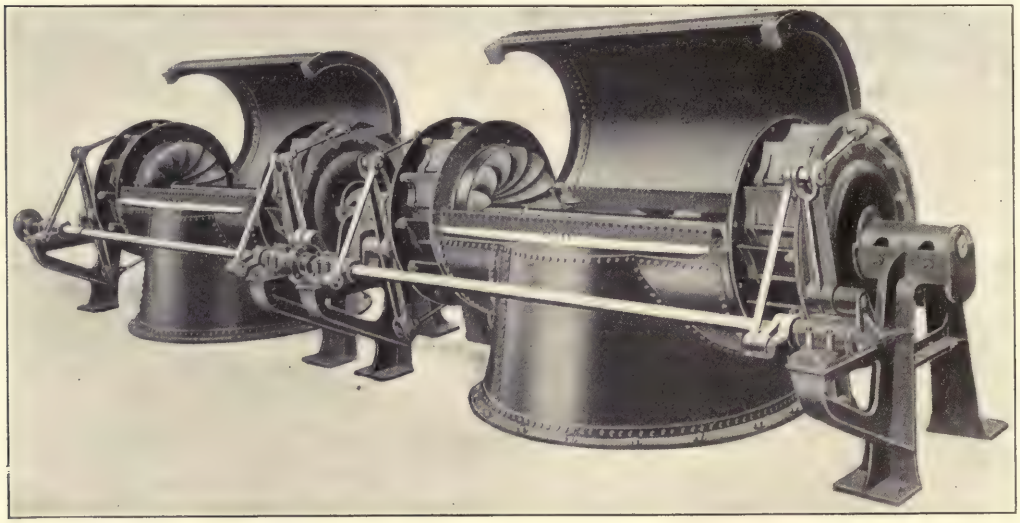


FIG. 1.—American Turbine as designed by the Dayton Globe Iron Works.

Low Head Turbine. In America, the low head turbine, a combination of Francis and Jonval type, is manufactured in the horizontal and vertical type, and is known as the American turbine. Frequently a number of runners are mounted on a single shaft, as seen in Fig. 1. In many cases they are placed in an open flume. The runner

[1] Hütte. Vol. I, p. 802. *Edition,* 18.

of this type of turbine was previously made of steel buckets riveted or bolted to the frames. To-day, most manufacturers make the runner in one solid casting. Fig. 2 shows such a runner.

The regulating mechanism of the American turbine, as manufactured by the Dayton Globe Iron Works, is shown in Fig. 3. The ring *C* which actuates the guides *D* controlling the water supply is governed through sector *E*. Other American low head turbines and application of same will be found throughout the text.



FIG. 2.—Runner of "American" Turbine.



FIG. 3.—Crown Plate and Gate of "American" Turbine.

Medium Head Turbines. As the line of demarcation between low and medium, and medium and high head, is not distinctly drawn, one will find under this head a great variation of turbines, including high and low head types. The majority of turbines used under medium head are of the Francis type. It is not the purpose of this book to go into details of the design of turbines; only the typical features will be given.

The Francis turbines are built in either the horizontal or vertical type, with one or more runners mounted on a single shaft. These turbines are placed, either in an open chamber of the power house, or inclosed chamber made of cast iron or structural steel. Figs. 5 and 6 show a vertical Francis turbine as built by J. M. Voith, Heidenheim, Germany, for the Kykkelsrud plant, Norway. It operates under a head of 52.5 feet to 62.5 feet, with a water consumption of 670 to 530 cubic feet per second, and with 150 R.P.M., develops 3000 HP. It will be noticed that the turbine casing is spiral in plan and rectangular in elevation; it is made of structural steel. The water enters the turbine casing with a velocity of 9 feet per second, and gradually increases to 20 feet, and discharges with a velocity of 3.9 feet per second. The runner has a diameter of 5.9 feet, and is mounted on a 12-inch vertical shaft, 25 feet long, on the end of which is coupled the shaft of the generator. Between the turbine and generator is a thrust bearing, supplied with oil at 220 pounds pressure per square inch, to take up the weight of the revolving element which is 32 tons. The water supply in the turbine is controlled by clam-shell gates.

A turbine of same make and pattern as the above will be found in the plant of the Ontario Power Company, with the exception that two turbines are mounted upon a horizontal shaft (see Fig. 7).

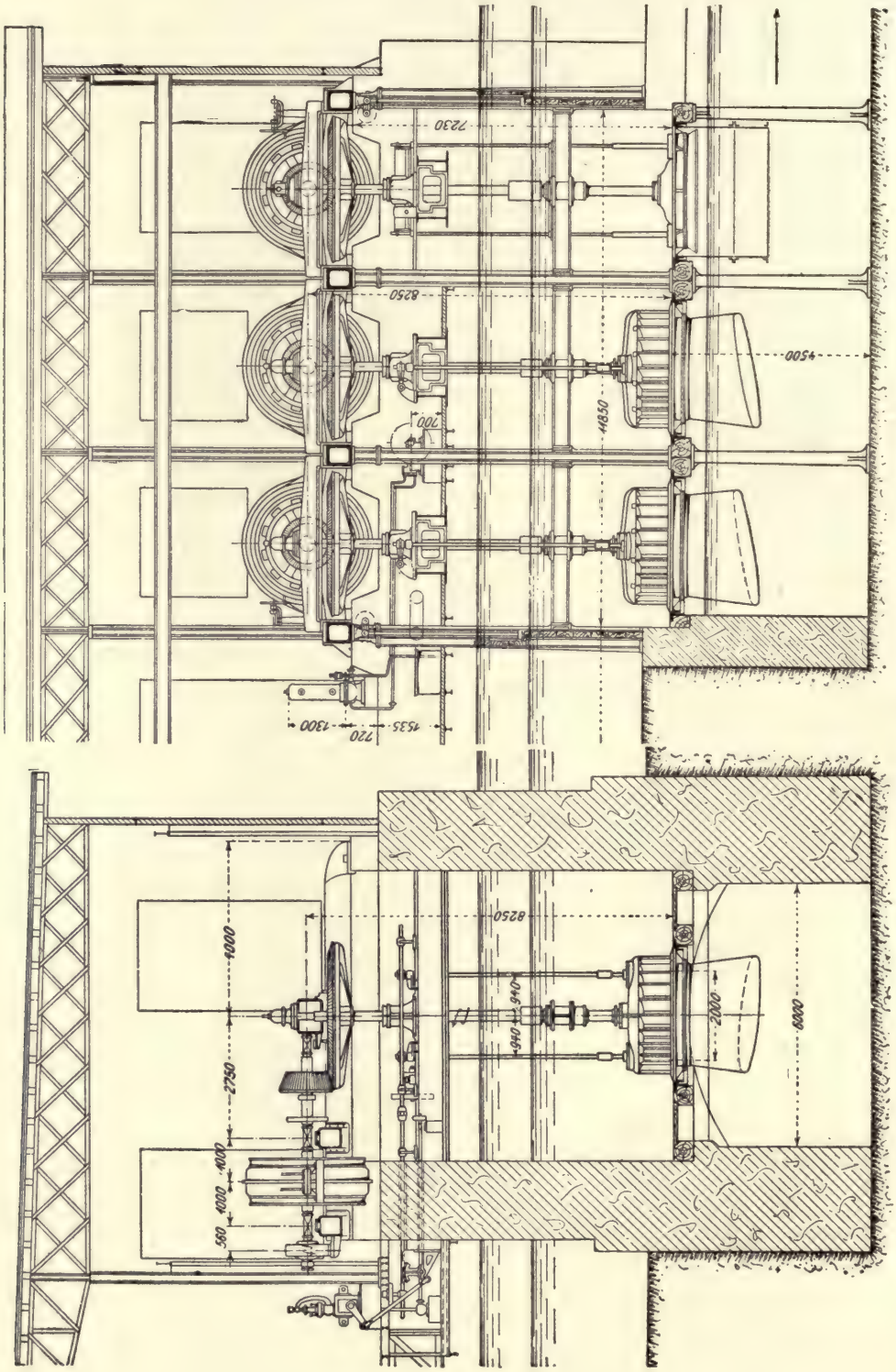
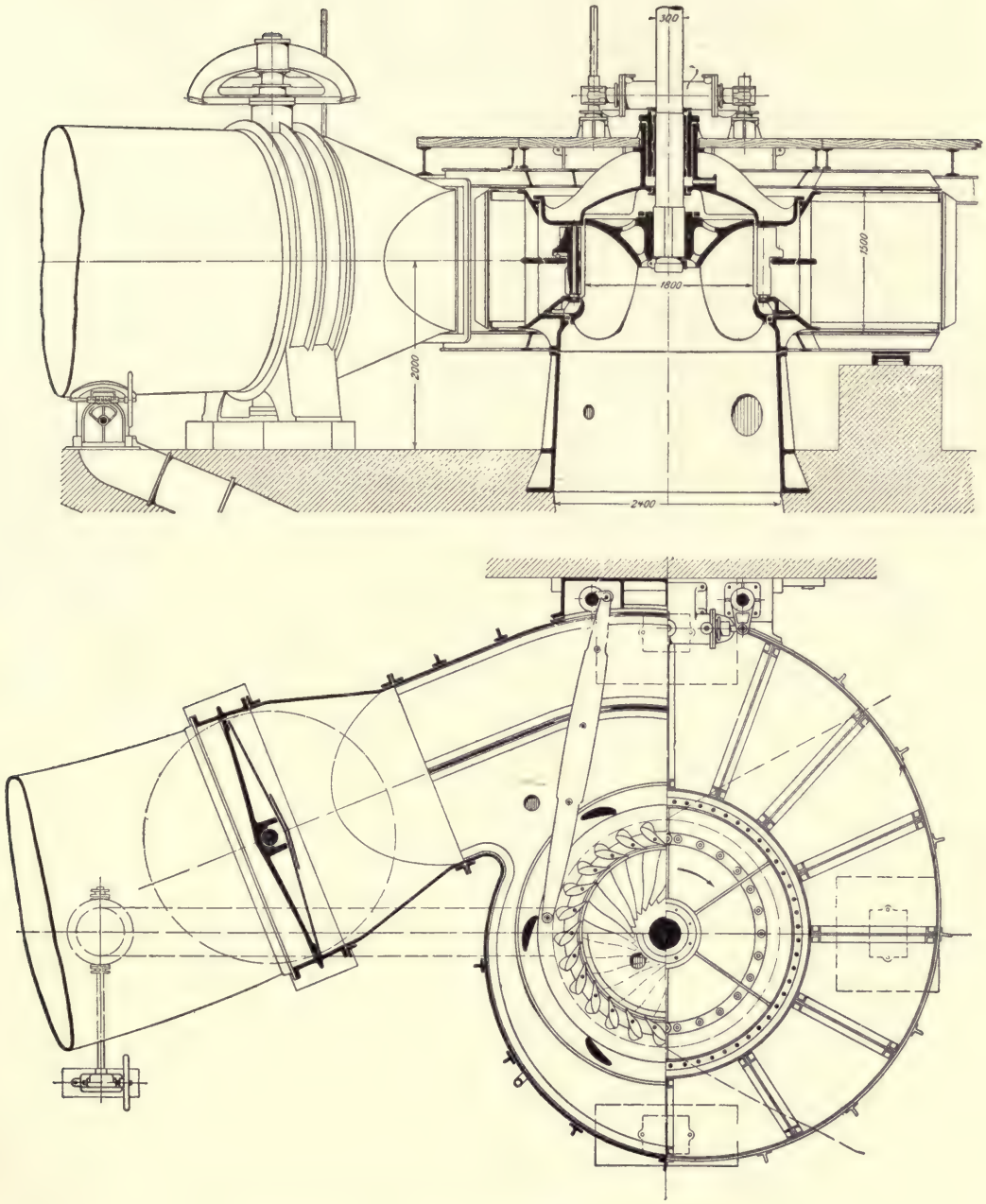


FIG. 4.—Low Head Plant at Schaffhausen, Switzerland.



FIGS. 5 and 6.—Voith Vertical Shaft Francis Turbine.

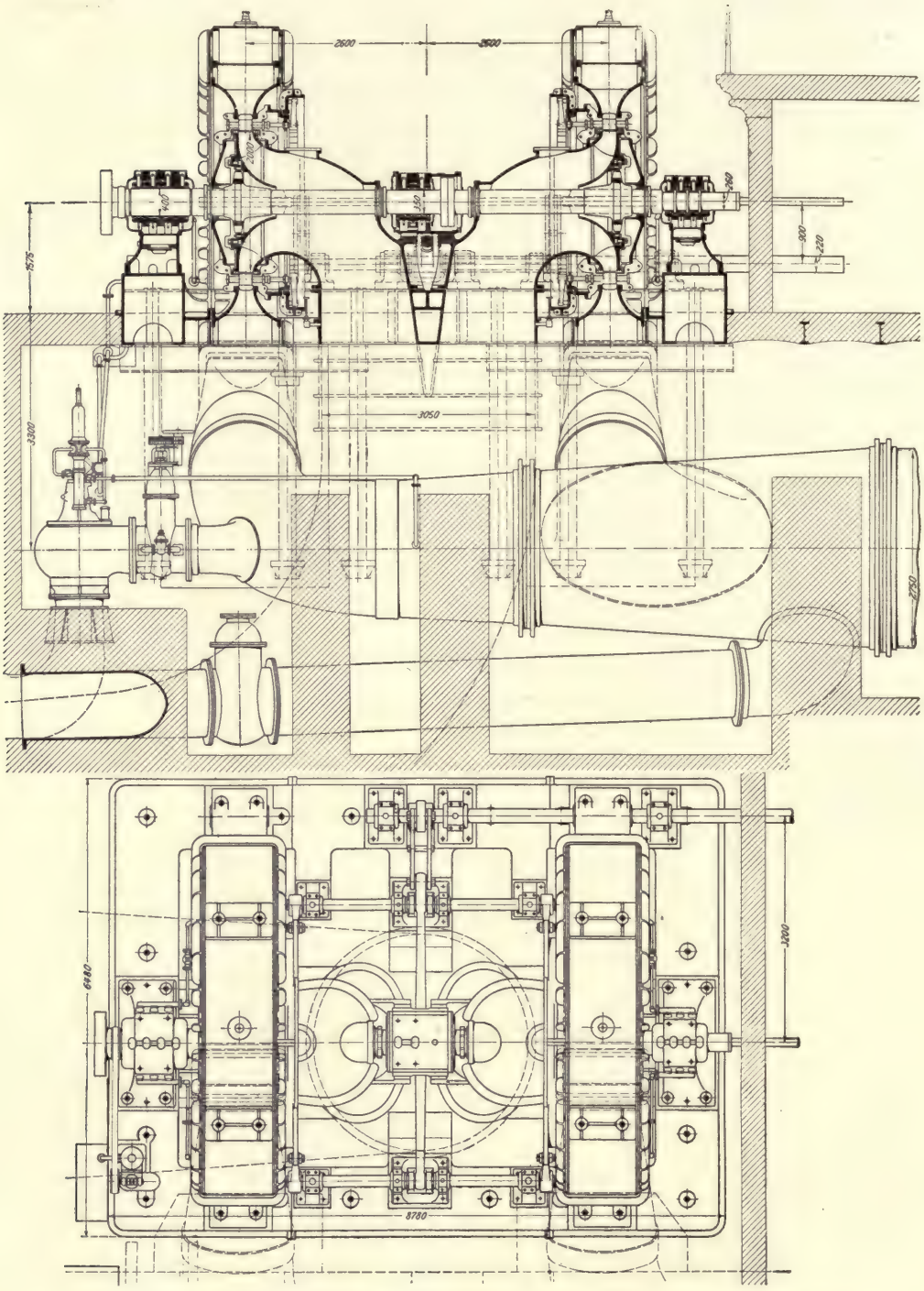
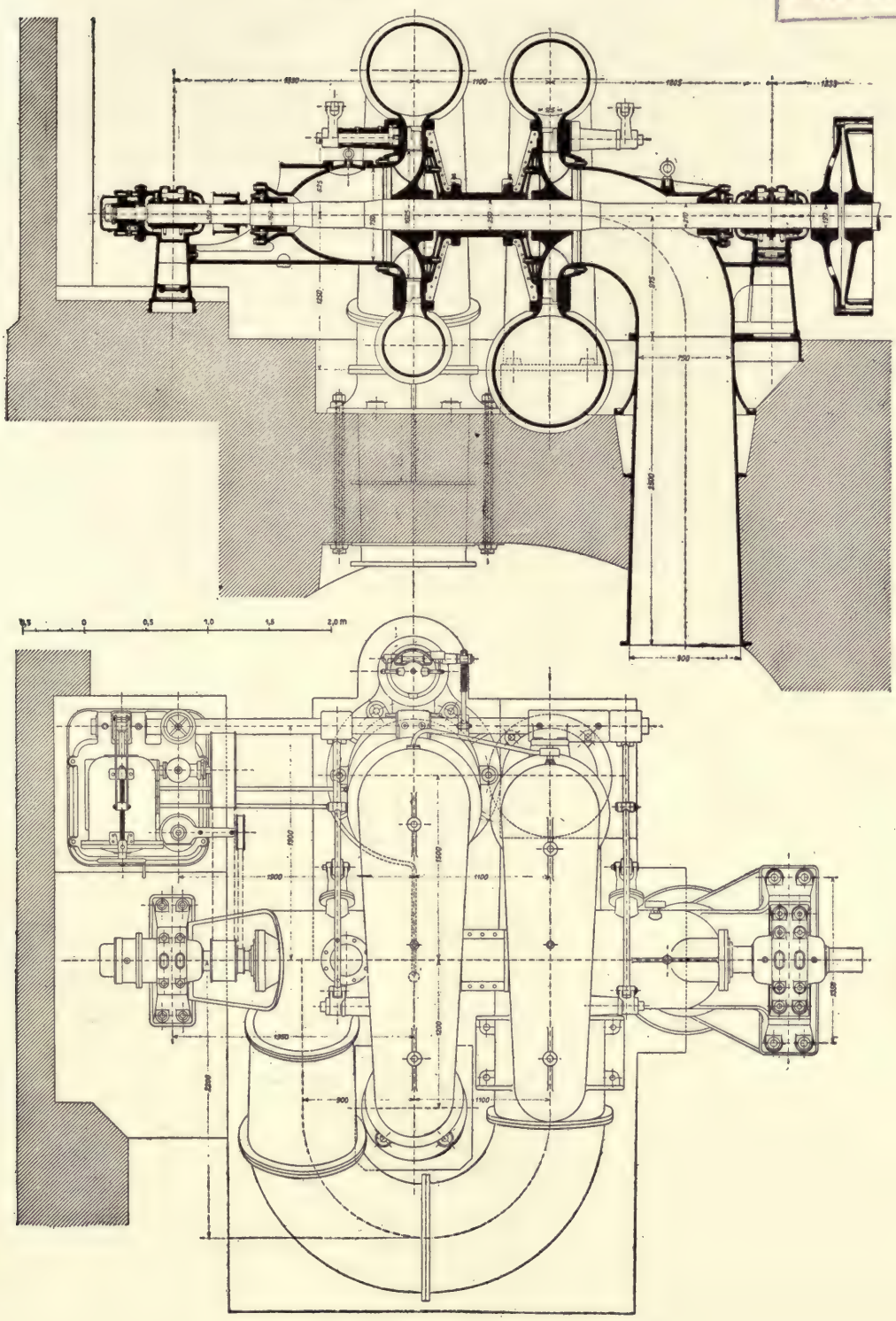


FIG. 7.—Plane and Elevation of Voith 11,340-HP. Double Spiral Francis Turbine, Ontario Power Company.

A.E.&M.E
UNIV. OF CAL



FIGS. 8 and 9.—Compound Francis Turbine.

A very interesting medium head turbine is installed at Wiesberg, Tyrol,[1] and is the first of its kind ever attempted. As it shows high efficiencies, it bids fair to be adopted. The reasons for adopting it are as follows: in the above-mentioned plant there were installed three Francis turbines of 1500 HP. each, operating under a head of 285 feet, making 300 R.P.M. During the operation, much erosion was observed,

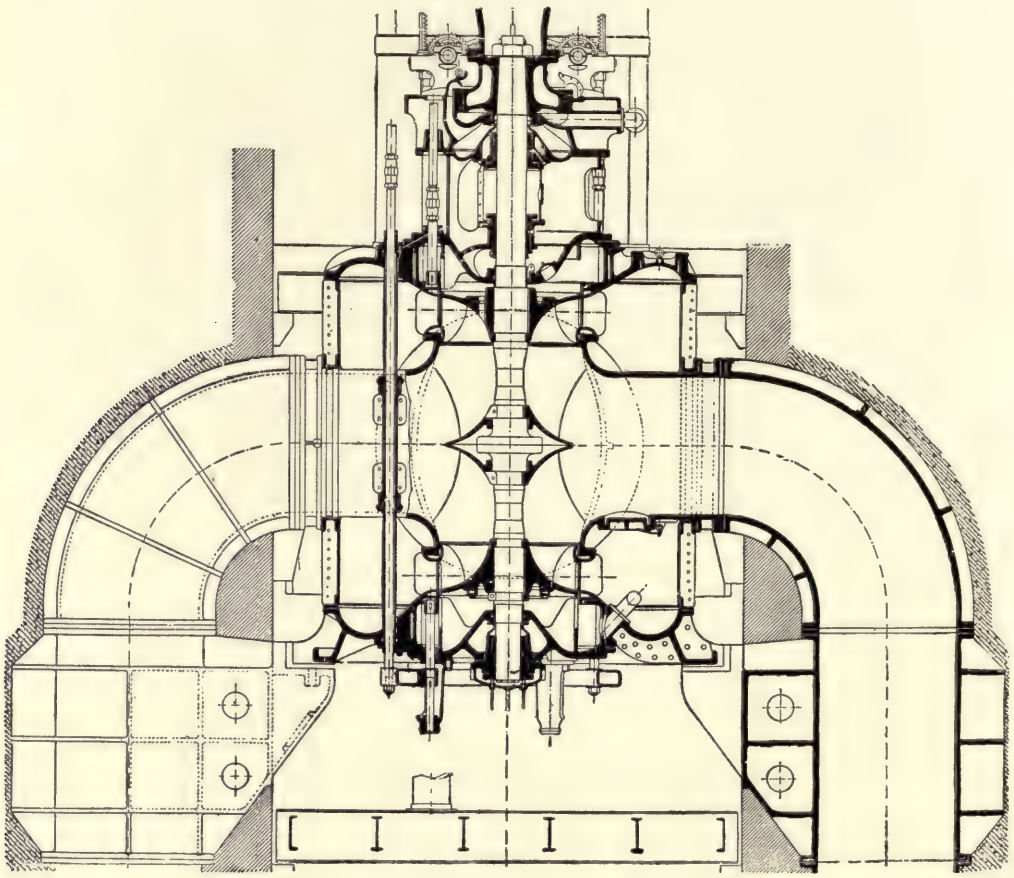


FIG. 10.—Escher Wyss 10,000-HP. Turbine of the Niagara Falls Power Company.

and the turbines lost their efficiency due to increase of clearance between the runner and the guides. As these turbines are fed by glacier water, which in the summer contains much sand, the erosion still continued during the winter months, when the water is entirely free from same.

[1] Zweistufige Verbundturbinen der Zentrale, Wiesberg in Tyrol, by Professor Pfarr. Schweitzerische-Bauzeitung, Sept. 14, 1907.

Prof. Julien Dalemont of the University of Freiburg, after making extensive investigations on the abnormal erosion on a number of hydraulic turbines, operating under different heads and with different speeds, published his results in a sixty-page pamphlet entitled, "L'Eclairage Electrique," Paris. An abstract of this paper, with many illustrations, is given by Edward P. Buffet in "Power and Engineer" of Aug. 4, 1908.

The turbine built by Kolben & Co., Prague, Bohemia, to overcome the effect of erosion, is a compound turbine of the Francis spiral type as seen in Figs. 8 and 9. It consists of two turbines mounted on the same shaft, so interconnected that the discharge of one becomes the supply of the other, thus reducing the head on each turbine from 285 to 142.5 feet. The spiral casing of each turbine is of cast iron and made in two parts with an inlet of 33.5 inches diameter. Both runners are 41.25 inches in diameter and of cast steel, and have 19 vanes. With a water consumption of 88 cubic feet per second, the compound turbine developed 2260 HP., making 342 R.P.M., giving, with a gate opening of 30, 60 and 90 per cent, efficiencies of 67, 81 and 86 per cent respectively. After the turbine had been in operation one year, it was inspected, and no evidence of erosion was found; in fact, much of the original coating of paint on the vanes was still intact.

As already stated, the turbines at Niagara Falls are considered as medium turbines. It will be observed that they are located in a pit directly above the tailrace. The water enters the cylindrical turbine casing on the side and discharges at 90 degrees through 2 draft tubes into the tailrace. A detail of the turbine installed in the plant of the Canadian-Niagara Falls Power Company is seen in Fig. 10. It is of the double Francis type surrounded by a cylindrical structural steel casing. The runners are 5.25 feet in diameter. When making 250 R.P.M. under a head of 131 feet, with a water consumption of 884 cubic feet per second, the turbine develops 10,000 HP.[1]

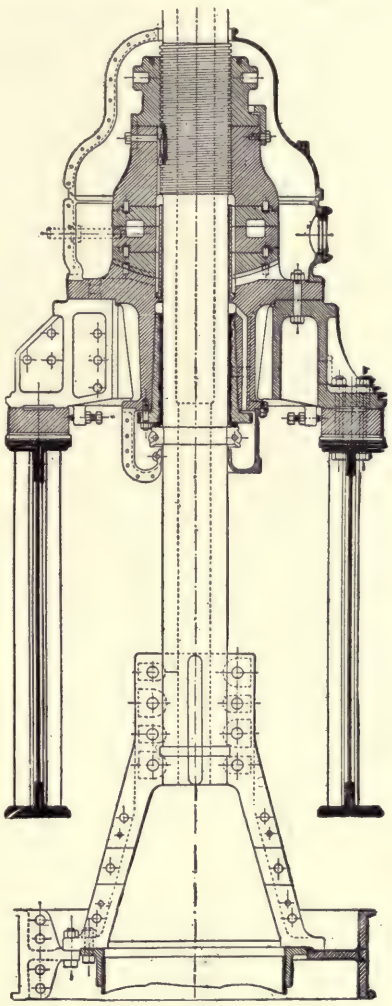


FIG. 11.—Thrust Bearing and Pipe Shaft Connection of Niagara Falls Power Company's Turbines.

As the turbine is set very deep in the pit, the shaft is made up of three sections, at the junctions of which are side bearings; the sections themselves are partly made up of steel pipe. At the upper section is a thrust bearing (Fig. 11), 36 inches in diameter, supplied with oil under a pressure of 367 pounds per square inch. The entire revolving element, including that of the generator, weighs 132 tons. The weight is also partly balanced by the runner disk, the remainder is taken up by a relief piston, 3.8 feet in diameter.

[1] Schweizerishe-Bauzeitung, 1904. Vol. I, p. 4. Wagenbach, Turbinenanlagen, p. 53.

High Head Turbines. Among the high head turbines, the Francis and impulse type are the most universally used. Probably the highest head developed is that at Vouvry near Lake Geneva, Switzerland,[1] where a plant has been constructed for a maximum capacity of 20,000 HP. The present equipment consists of four 500-HP. and one 2700-HP. turbine, which operate under a head of 3116 feet.

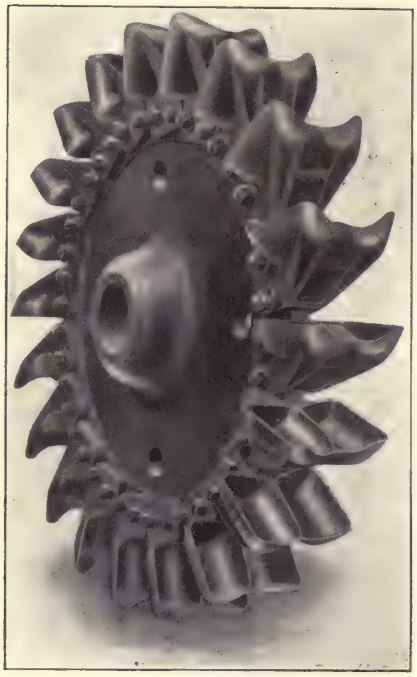


FIG. 12.—5000-HP. Pelton Wheel.

In America, of the high head turbines used, the impulse wheel is the most prominent; they are manufactured by several concerns, notably the Pelton Water Wheel Company. This turbine is a very simple machine; it consists of a wheel with a number of buckets circumferentially mounted. The wheel is usually mounted on a horizontal shaft, in some cases on a vertical; and one or more wheels mounted on a single shaft. The water from the penstock is directed against the buckets through one or more nozzles with round openings.

A typical installation of a Pelton wheel is shown in Fig. 13, as installed for the Telluride Power Company, near Salt Lake City, Utah.[2] The shaft of the unit is mounted on three bearings, one on each side of the generator and one on the outside of the wheel. The outboard generator bearing, built by the Pelton Water Wheel Company, is 9 inches in diameter, and is of the machined ball-and-socket type. The bearing is in a tight case partially filled with oil, which is carried up on the shaft by loose rings riding on the latter, the boxing having a lower half only. Each water wheel is a forged steel disk, on the periphery of which are mounted 24 cast-steel Pelton tangential buckets. The wheel making 300 R.P.M. operates under an effective head of 1750 feet at low stages in the reservoir, and under a maximum effective head of 1775 feet. Water is supplied to each wheel through a separate Pelton needle deflecting nozzle. The size of the stream applied to the buckets is hand regulated, by means of the needle part of the nozzle, through a standard mounted on a floor directly over the rear end of the nozzle. For changes in the speed of the wheels, each nozzle is deflected by means of a Pelton pilot control apparatus, mounted on the floor in front of the unit.

If it is desired to throw the water off the buckets in order to shut down the wheel, this may be accomplished by turning the hand wheel on the control in a counter-

[1] Wagenbach. Turbinenanlagen, p. 3.

[2] A Hydro-electric Development in Utah. *The Engineering Record*, March 14, 1908.

clockwise direction, so that pressure is applied to the top of the piston in the cylinder under the nozzle and released at the bottom.

The pair of deflecting nozzles for the two wheels are attached to a Y-connection at the end of the pressure pipe embedded in the mass of concrete under the rear end of the building. Each branch of the Y is fitted with an hydraulically operated gate

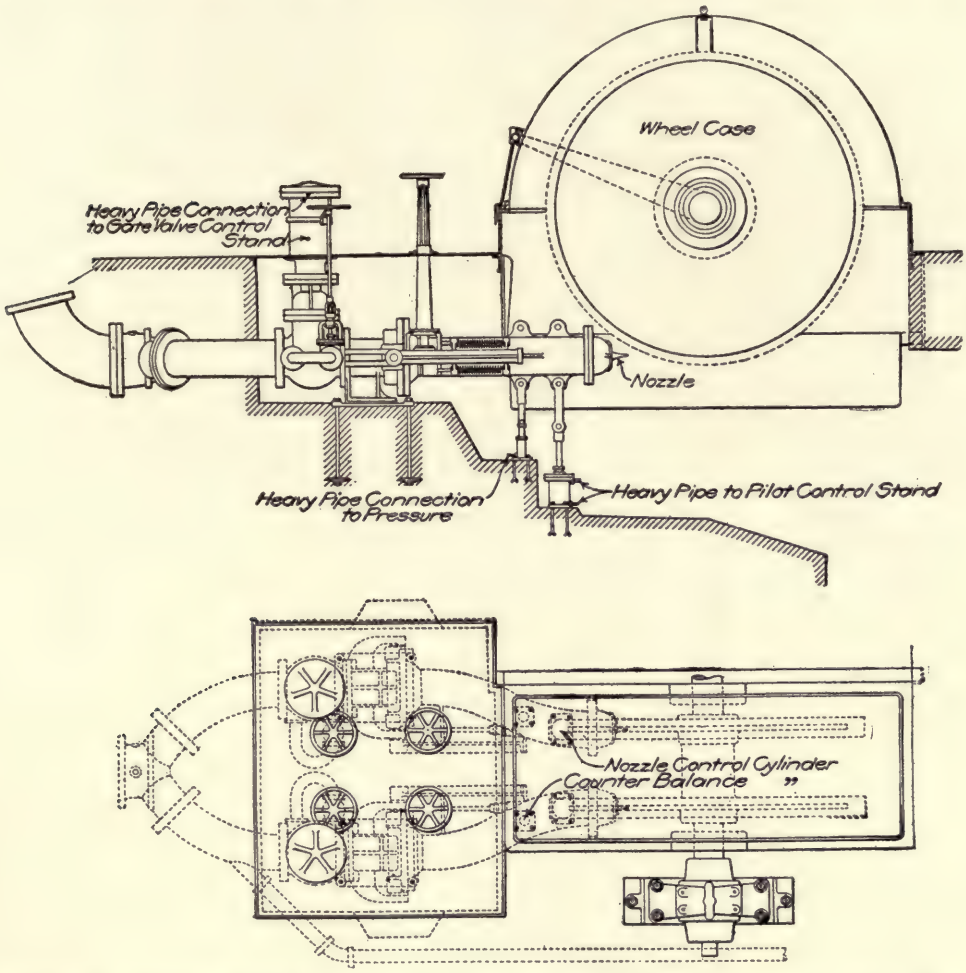
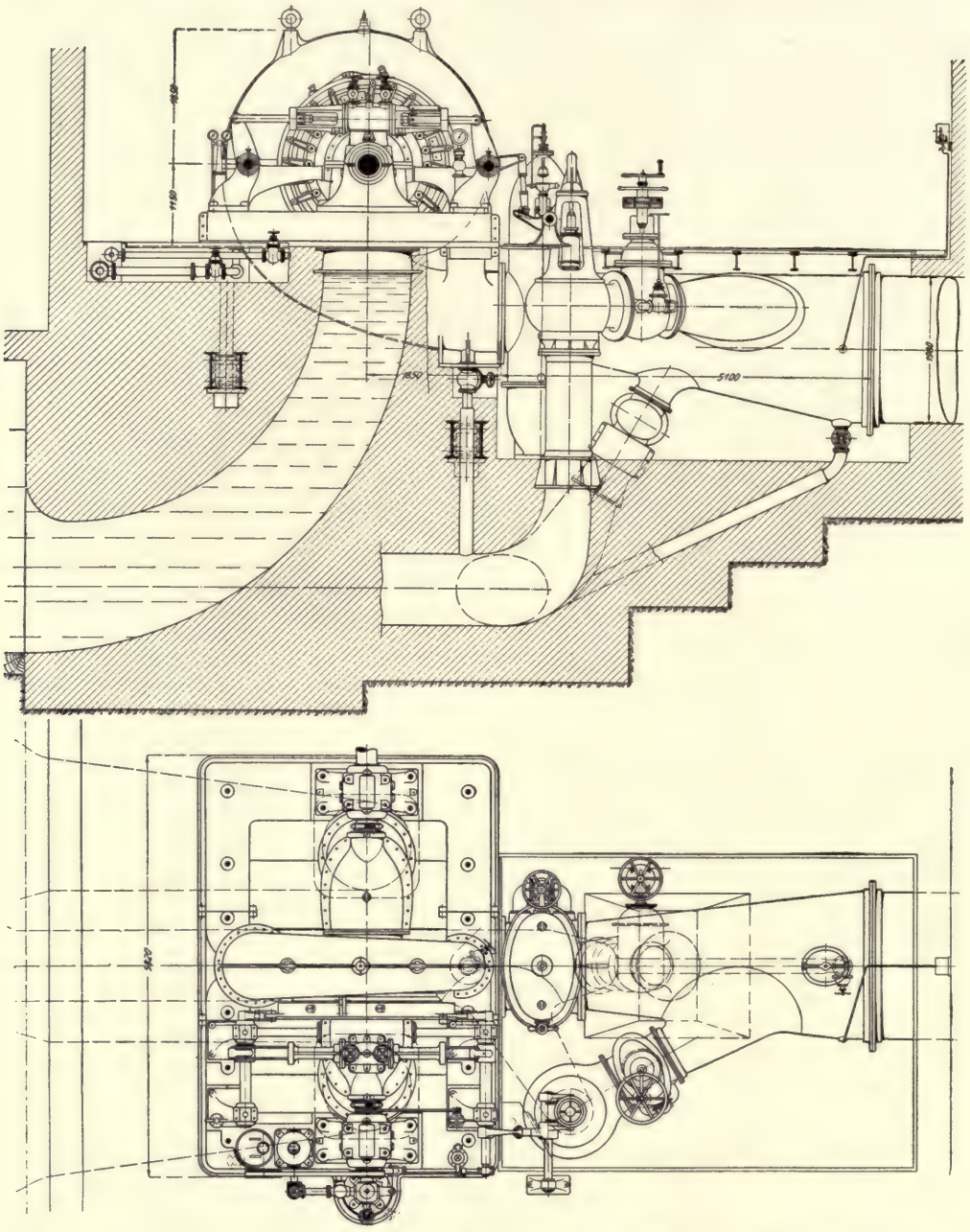


FIG. 13.—Pelton Wheels installed for the Telluride Power Company, Salt Lake City.

valve, placed in a covered pit in the concrete at the rear of the wheel case. The operation of each of these valves is controlled by a hand wheel mounted on a standard on the floor at the rear of the unit. In order to avoid any disastrous effects from water hammer in the pressure pipe, caused by a rapid closing of these valves, or by other conditions, a relief valve is placed in a connection to the line directly back of the junction of the branches of Y.

The discharge from the nozzles, when diverted from the buckets, is directed against a curved baffle plate set in the end of the concrete which forms the pit under



FIGS. 14 and 15.—Voith 6100-HP. Spiral Francis Turbine. Hamilton Cataract Company.

the wheels. This baffle plate is arranged so that the streams striking it tangentially are deflected 90 degrees. The stream is thus thrown into a deep splash pit, where its remaining force is absorbed and the water delivered to the tailrace practically quiet.

As will be seen from the foregoing, the Pelton wheel is provided with round nozzles, the regulation of which is discussed under "Governors." The European

impulse wheel is frequently provided with nozzles of square or rectangular openings; the construction of the buckets varies slightly according to the nozzle.

The wheels are mounted either on horizontal or vertical shafts. As has been pointed out, some of the first impulse wheels constructed were mounted on a vertical shaft, similar to those recently installed at the Necaxa plant, Mexico, which operate under a head of 1300 feet.

Figs. 14 and 15 show a 6100-HP. turbine as installed for the Hamilton Cataract Company. It is of the Francis spiral type, operates under a head of 261 feet, making 286 R.P.M., and has two draft tubes. The runner has a diameter of 4.9 feet. The vanes are made of phosphor-bronze and the hub of cast steel. The regulation is accomplished by an oil-operated hydraulic governor, which, in case the load is suddenly thrown off, diverts part of the water through a by-pass, then gradually shuts off the supply, thus preventing water hammer. Tests show that by throwing off from full load one-third, one-half, two-thirds of the load, the speed varies 1.1, 1.6, and 3.5 per cent respectively. Further, the turbine shows an efficiency of 85.8 per cent at full gate and 86.8 per cent at three-quarters gate.

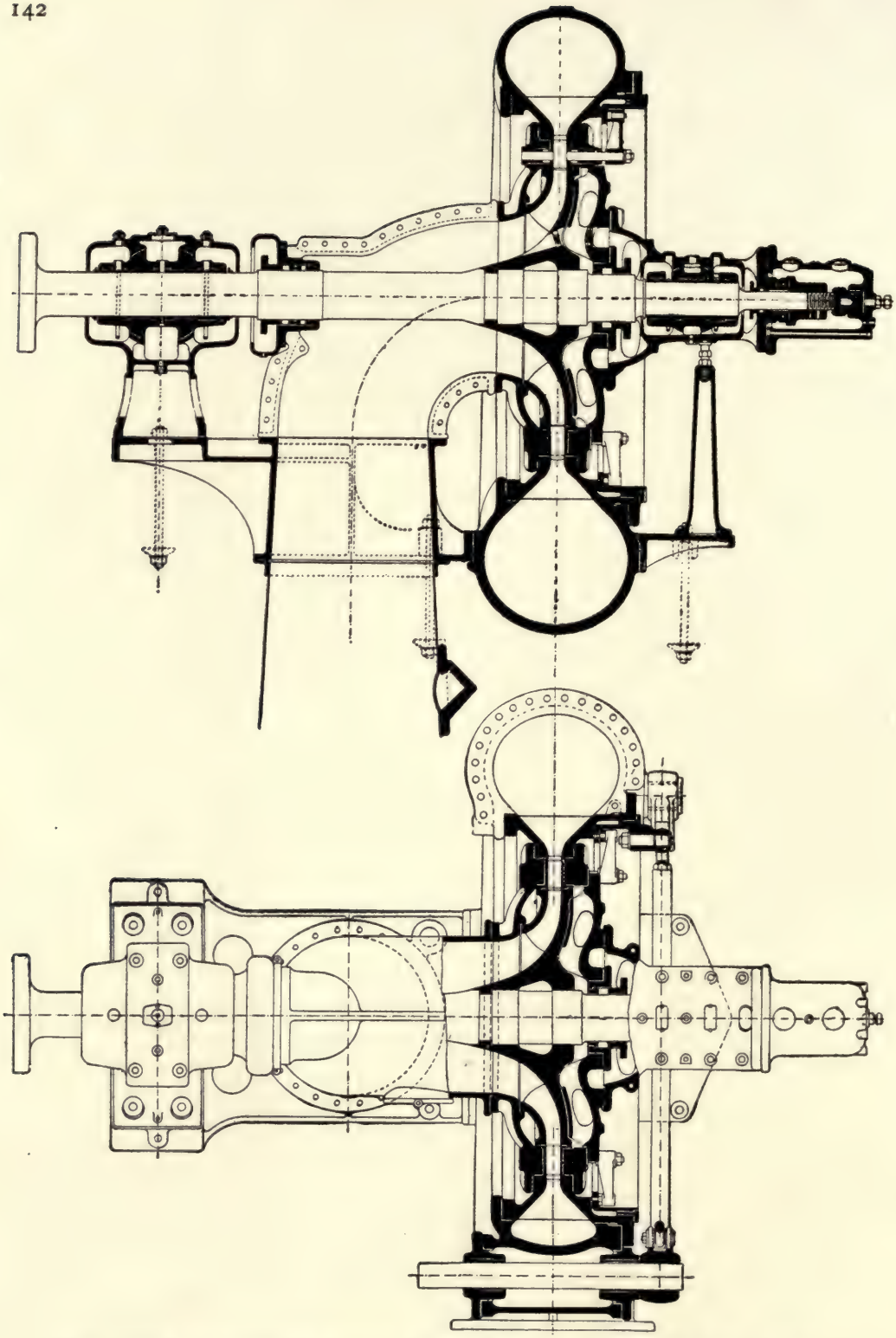
Draft Tubes. Whenever possible turbines should be equipped with draft tubes in order to secure additional head, which would otherwise be lost. There are instances where impulse wheels have been provided with draft tubes. However, when so equipped, impulse wheels run in partial vacuum; the water column in the draft tube must be so regulated that it is always a few feet below the runner; therefore near the junction of the upper end of the draft tube and the turbine there must be located an air cock which is controlled manually or by the governor. This arrangement is preferable for small wheels and particularly where, owing to ground water or other reasons, they cannot be located near the tailrace. Such an installation will be found at Chur, Switzerland, where 250-HP. wheels operate under a head of 272.5 feet. They are provided with two needles. The head gained by the use of the draft tube is about 15 feet.

The theoretical length of a draft tube is equal to perfect vacuum or 34 feet. Owing to losses due to velocity, friction, etc., in the draft tube, which cannot be counteracted, perfect vacuum is never realized. In practice, the height of the water in the draft tube decreases with the increase of diameter of same and vice versa. The following table is abstracted from Meissner [1] and converted into English units; the dimensions as given are in round numbers.

TABLE I.—HEIGHT OF DRAFT HEADS.

Diameter of draft tube in feet.	Draft head in feet.	Diameter of draft tube in feet.	Draft head in feet.
1	30.0	6	17.0
2	27.0	7	15.5
3	24.0	8	14.0
4	21.5	9	13.0
5	19.0	10	12.0

[1] Meissner, Hydraulische Motoren, Vol. II, p. 212.



FIGS. 16 and 17.—9700-HP. Francis Turbine, 550 feet Head, 400 R.P.M., for the California Gas and Electric Corporation. Allis Chalmers Company.

Draft tubes should always be made conical, so as to gradually reduce the velocity of discharge, and must, on the upper end, be of the same size as the discharge opening in the turbine casing, to avoid any abrupt changes in the velocity of the water. The velocity of discharge from a draft tube should be about 2 feet for low-head, 3 feet for medium-head, and 4 to 7 feet for high-head turbines. Draft tubes should be straight and free from turns as possible; this is particularly true of long draft tubes. The end must be watersealed, at least some 6 to 12 inches at low water level for small-sized tubes, and 18 to 24 inches for large ones. Draft tubes are made of cast iron, structural steel, or are part of the concrete foundations. When made of metal, they must be made strong enough to stand atmospheric pressure (perfect vacuum is equivalent to a water column 34 feet high or a pressure of 14.7 pounds per square inch) and any pulsations which might arise by starting and running turbine under great variations of load; for the latter reasons a long draft tube must be properly anchored.

REGULATING DEVICES.

Principle of Governors. Turbines and water wheels in general, coupled to generators, must be provided with governors of proper design, to regulate same so that the speed will be nearly constant. The irregulation in a hydroelectric plant may have its origin in the hydraulic end, such as water hammer and surging in the penstock or draft tube, loss of vacuum in draft tube, etc.; in the mechanical end, poor operation of the turbine and the supply gates, controlling of waste water in case of a sudden shut down, which might arise from the hydraulic, mechanical, or electrical end of the station.

There are, of course, other factors which necessitate the choosing of a governor adaptable to control load fluctuation for the particular plant; for instance, successful operation of a high-head plant may be accomplished either by quick-acting or slow-acting governors. Where the load on a plant is steady, a slow-acting governor gives best results. In addition to a governor the turbine may be provided with a special fly wheel. The runner of the turbine, or the field magnet of the generator, is designed to serve the same purpose, that is, preventing water hammer in the penstocks and other irregularities in operation. A plant with great load fluctuation is best regulated by a quick-acting governor; but a governor of this kind must be provided with auxiliaries to by-pass the water into the tailrace, as otherwise the sudden cut-off of a moving column of water will set up violent surges and liability of damage to governor as well as the penstock. As this by-pass water is always wasted, a governor should be designed to close soon after the turbine is cut off. A type of such a governor is seen in Fig. 1. This turbine is of the impulse type as installed in the Brusio plant. As will be seen, the nozzle is stationary, while the needle is moved forward and back by a piston controlled by the governor, which also actuates the by-pass located in the continuation of the penstock.

The regulation acts as follows: when the water to the wheel is cut off by the needle the by-pass opens at the same time and closes gradually, so that only little water is wasted; the main valve closes simultaneously with the closing of the by-pass.

Small fluctuations are taken up by the needle and by-pass. The main valve serves as relay. The duration of closing is set by a hand wheel on the governor. Tests show that by suddenly throwing off full load the speed variation is 10 per cent.

Another type of Swiss governor is shown in Fig. 2, as installed in connection with a 2500-HP. high-pressure turbine of the so-called "Spoon Wheel" type, operating under a head of 1023 feet, at Lucerne, Switzerland. The governor is operated by

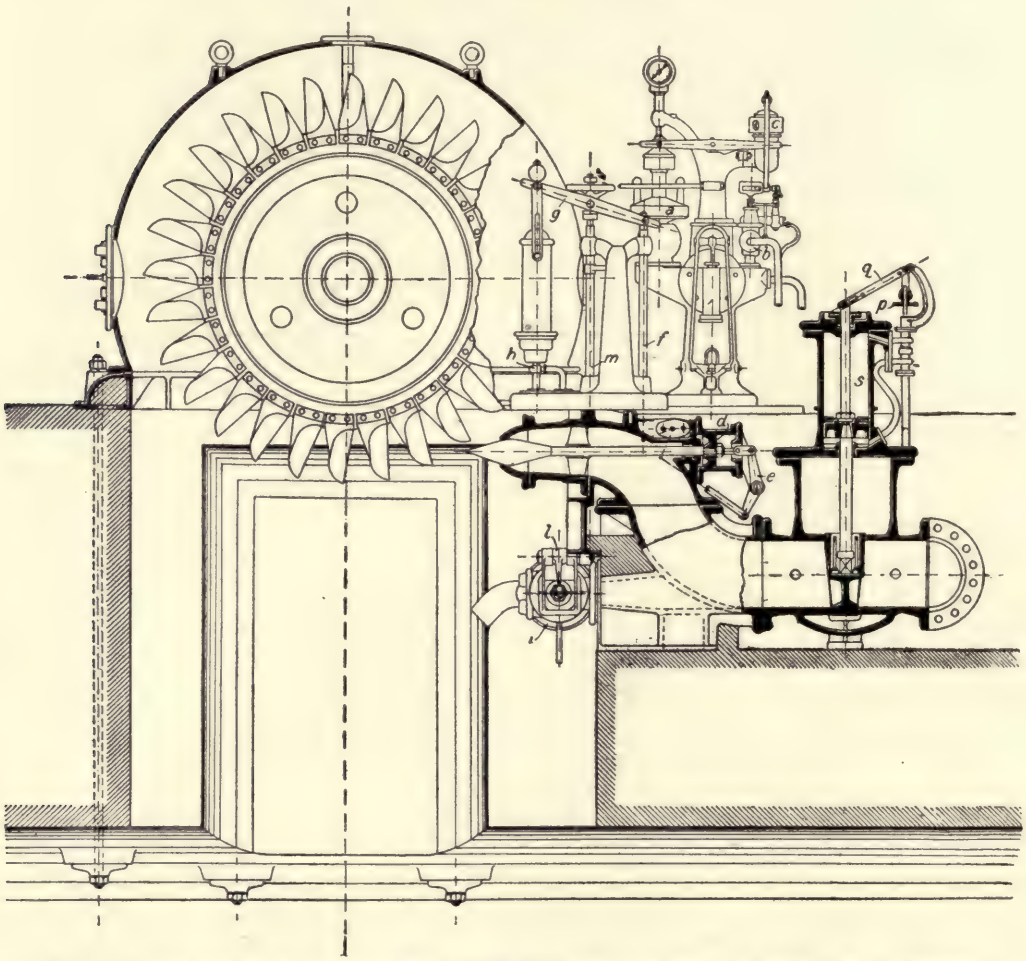


FIG. 1.—Escher Wyss Impulse Wheel with Non-Water-Wasting Nozzle and Regulator.

means of gearing from the main shaft, and adjusts the opening of the jet by means of an oil-actuated piston device.

The nozzle opening is 6 by 3.5 inches and is varied by a hinged jaw. The opening and closing action of the by-pass takes place simultaneously with that of the nozzle. Similar to that in the former mentioned device, the water is by-passed for only a short time before the main valve closes (see Fig. 3), which is automatically controlled. The closing this main valve can be regulated to 20 seconds, while the

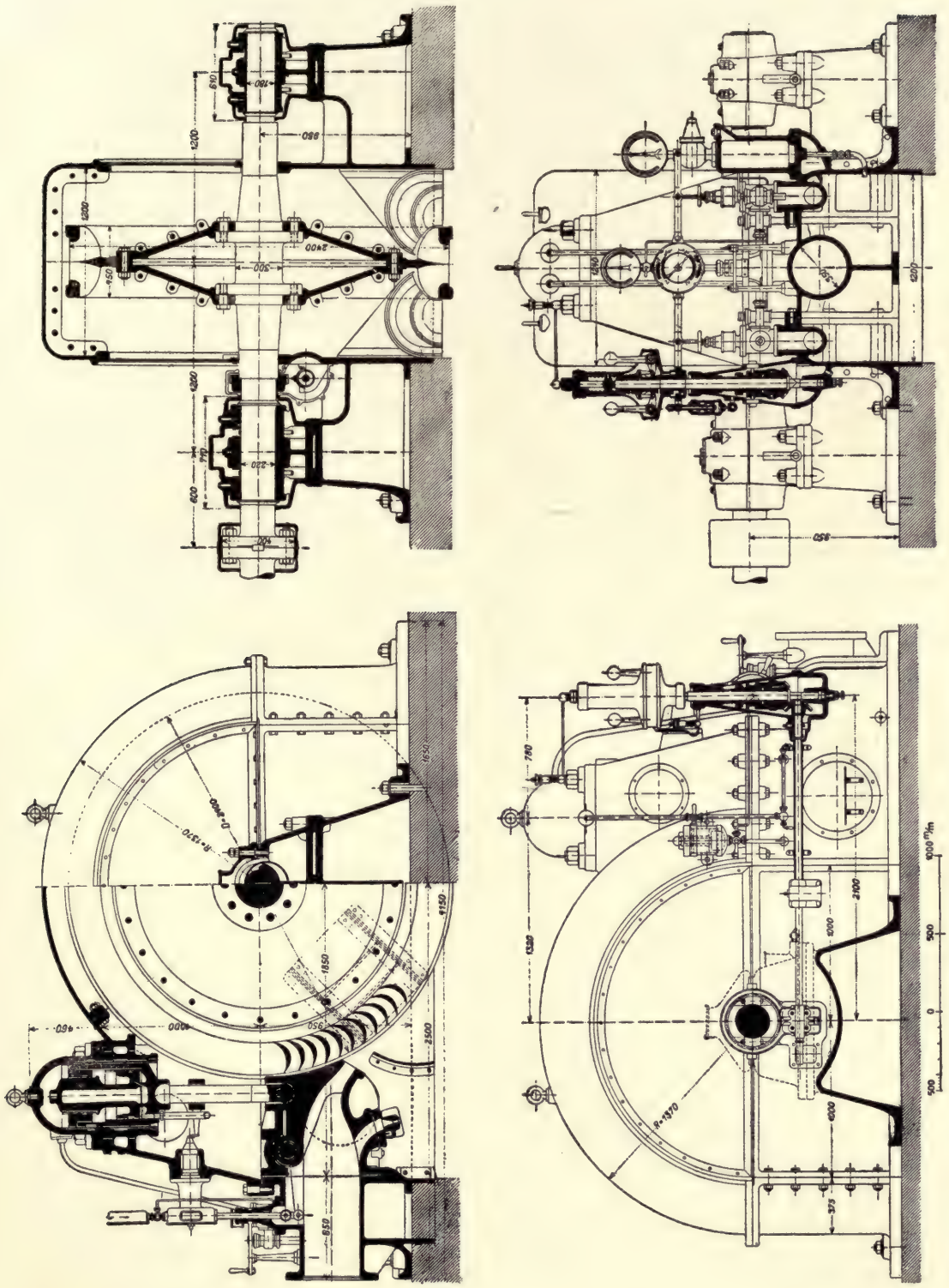


FIG. 2.—Bell Spoon Wheel Turbine and Governor, Obermatt Plant, Switzerland.

action of the governor, by throwing off full load (2500 HP.), requires 2 to 2.5 seconds, giving after 6 seconds a speed regulation of 4 per cent. The governor is provided with several indicators, one of which gives in per cent the nozzle opening and one the by-pass opening.

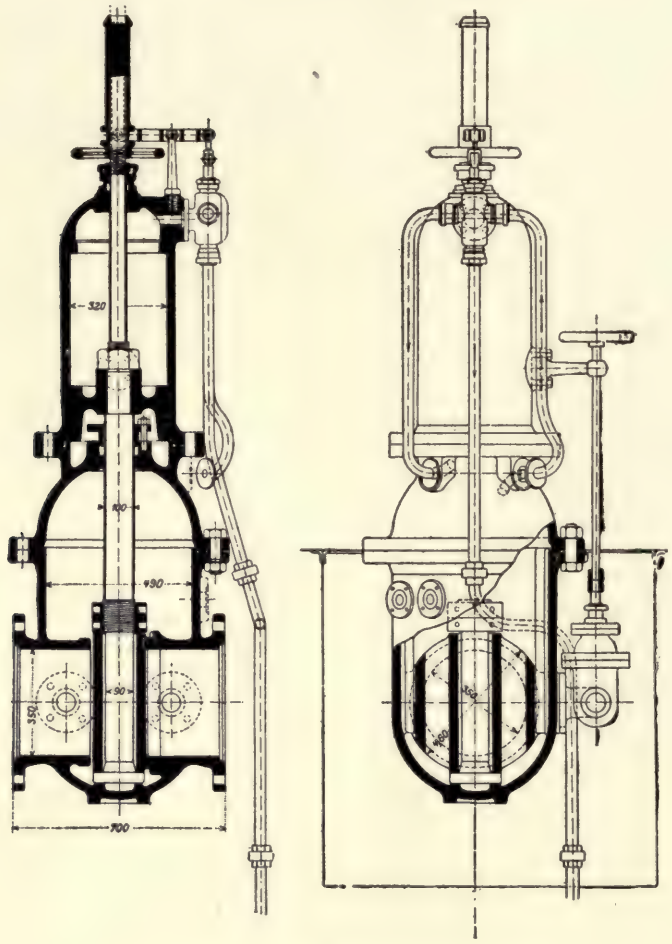


FIG. 3.—Automatic Main Turbine Gate.

Lombard Governor. The illustration, Fig. 4, shows a type of oil-pressure governors as manufactured by the Lombard Governor Company of Ashland, Mass. This governor consists essentially of three parts — the oil pump, the pressure and vacuum tanks, and the governing mechanism.

The centrifugal head shown distinctly at the upper right of illustration is belted directly to the turbine shaft. It controls a primary valve immediately below it. The oil, normally under 200 pounds pressure, which is received from the pressure tank, is allowed to enter a vertical 10 inch by 24 inch cylinder through an intermediate piston valve, which is controlled by the primary valve and a system of

unbalanced pressures. The oil exhausts from the cylinder through the same intermediate valve into the receiving tank. The pressure and vacuum are created by the pump, which can be either motor driven or belted to the turbine shaft. The motion from the piston rod to the gate mechanism of the turbine is transmitted by means of racks and gears.

A simple and effective anti-racing mechanism is used, whereby the action of the governor, however rapid, ranging from one to four seconds for full stroke of the piston, is rendered dead-beat.

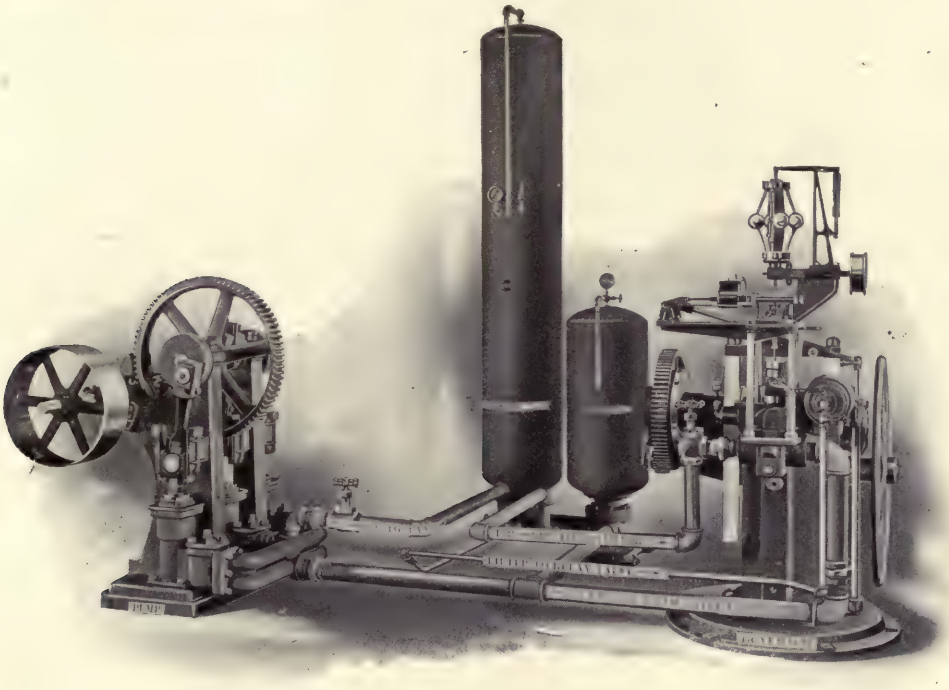


FIG. 4.—Lombard Governor.

A Lombard hydraulic relief valve is seen in Fig. 5. It is connected to the penstock near the turbine, and can be set for any excess pressure desired; it is claimed that it will operate on an excess pressure of one per cent.

Glocker-White Governor. This governor as manufactured by the I. P. Morris Company is seen in Fig. 6. One essential feature is the governor's centrifugal weights in the form of a boot, partially filled with mercury, which, when running at normal speed, is divided between two chambers. With an increase of speed the centrifugal force causes the mercury to flow from the lower to the upper chamber; thus the center of gravity increases in a greater ratio than the speed, and vice versa. The action is transmitted through a system of levers to a small pilot valve controlling a relay valve, admitting oil, under 250 pounds pressure, to the cylinder, which in turn actuates the turbine gates.

Replogle Governor. The Replogle governor[1] is purely mechanical in operation, the principle of which is given below.

"In the diagram (Fig. 7), *A* is a spherical pulley with its shaft turned down and threaded as at *X*. *B* and *B* are oppositely revolving concave disks lined with leather. *C* and *C* are lignum-vitæ pins flush with the leather. *D* and *D* are com-

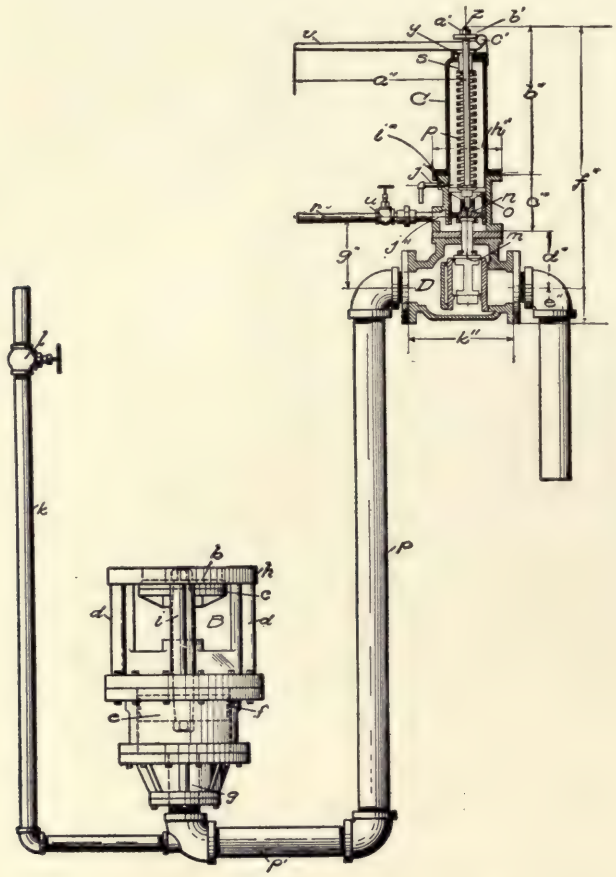


FIG. 5.—Lombard Hydraulic Relief Valve.

pression springs for causing the necessary pressure between the disks and the sphere. *E* and *E* are governor balls so poised as to require the weight of *A* to balance them at normal speed. *F* is a loose collar to allow independent revolution of the balls *E*, *E*. *G* is the point of connection between *A* and the gates or valves of the motor to be governed. *X* is the relay device, and is for the purpose of preventing racing, also for the purpose of properly dividing the load in parallel units. *Z* is a stationary spindle or connecting link between collar *F* and the threaded shaft or pulley *A*.

[1] Some Stepping Stones in the Development of a Modern Water-Wheel Governor, by Mark A. Replogle. A. S. M. E., Chattanooga, Tenn., May, 1906.

Z is only stationary in reference to revolution, as it rises or falls with the variations of the governor balls.

" The following is a description of the governor's action if the speed should drop by an addition of load, the lessening of the centrifugal effects on *E*, *E* will allow *A* to drop below the centers of disks *B*, *B*, which are constantly revolving in the direction shown in the diagram. As soon as *A* falls below the disk centers, it will begin

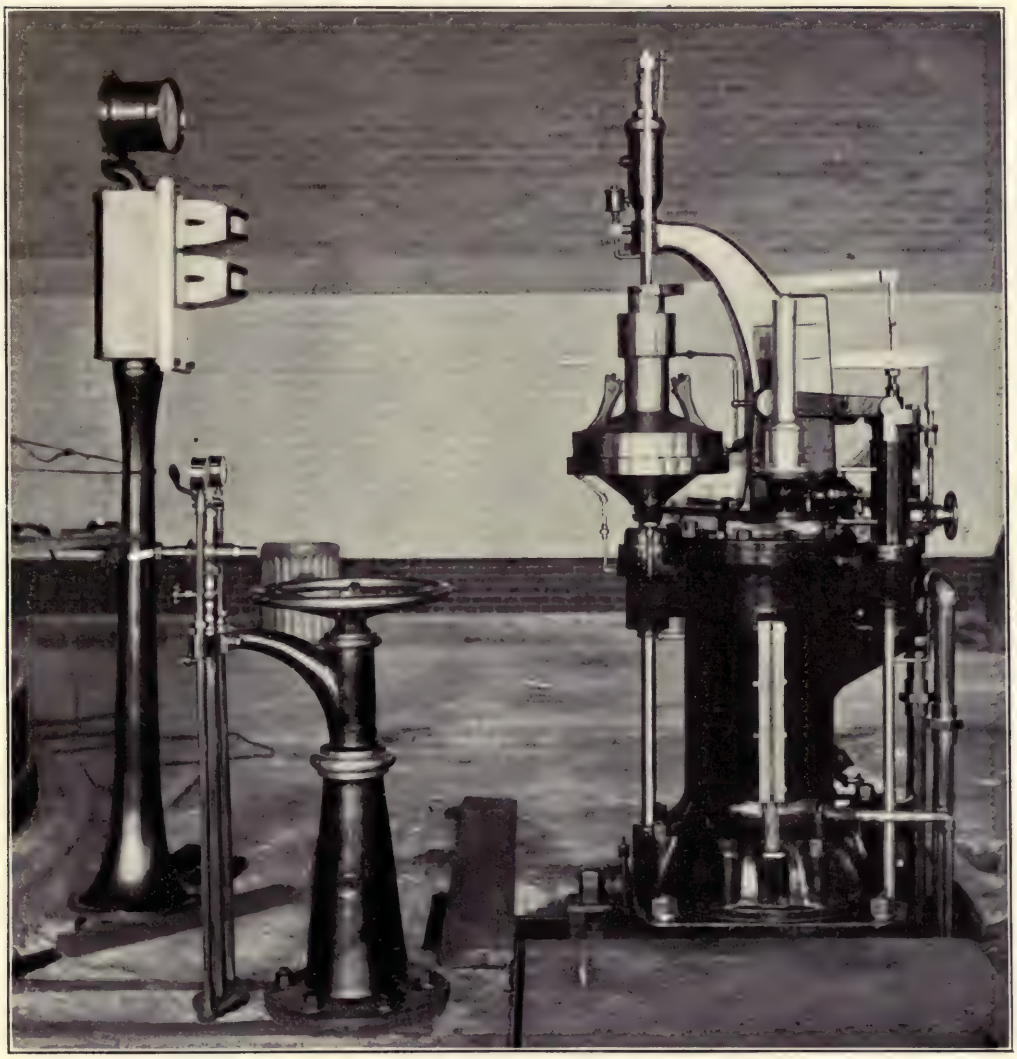


FIG. 6.—Glocker-White Governor (I. P. Morris Company).

to revolve slowly to the right, being the direction that will turn on power. While *A* is turning to the right it shortens the distance to collar *F* by means of the thread at *X*. This shortening causes *A* to be pulled back to the disk centers, thereby cutting the governor out of action. It will be noticed that *E* and *E* have not shifted their

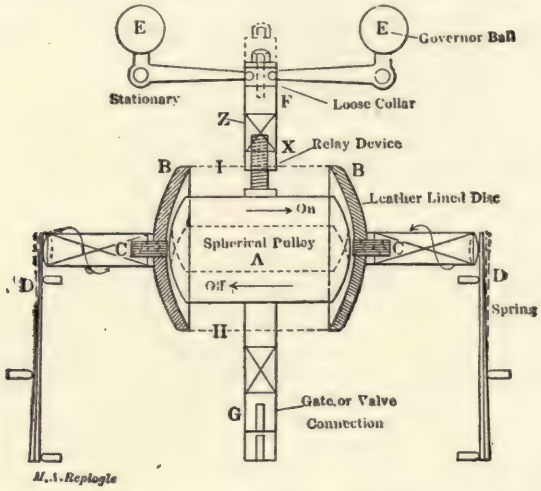


FIG. 7.—Replogle Governor.

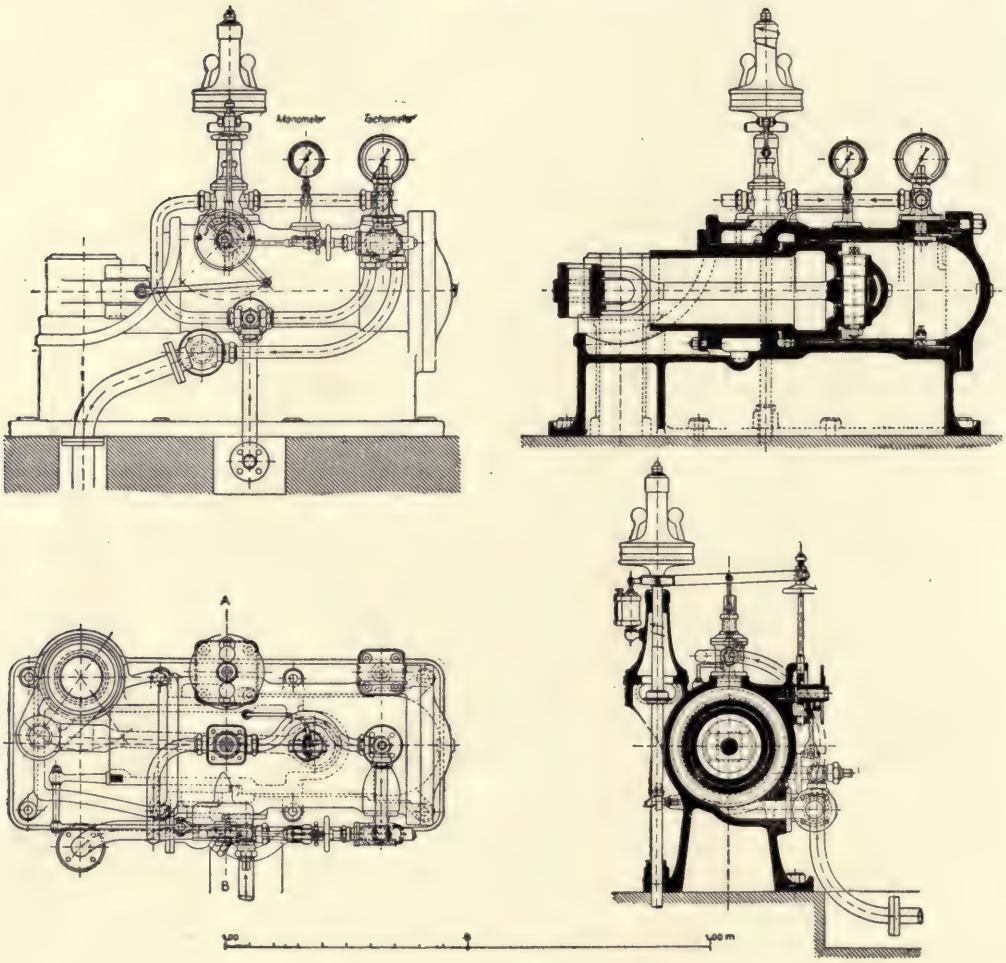


FIG. 8.—Pressure Regulator (Bell & Co.).

A.E.&M.
UNIV. OF CA

position during the act of opening the valves. Therefore the speed is in reality lower after the new power is added than it was before the change in load. It is now clear that there is a continuous dropping in the speed while the valves are opening. In practice this permanent drop is enough to insure the correct division of load. It is also enough to permit of successful government where adequate power storage exists in the unit to be governed. In this governor there is no special provision for temporary relay. Such provision is unnecessary except where the momentum effects are small. (In the governor shown the permanent drop can be varied by the pitch of the thread used at *X*.) In ordinary practice it is about 2 per cent."

Pelton Nozzle Regulation. The usual method of controlling the speed of the Pelton wheel is by means of a deflecting nozzle, needle nozzle, or a combination of both. Which one of these types is most suitable depends on the condition of the head, power and character of load.

The deflecting nozzle is a cast-iron nozzle provided with a ball and socket joint, permitting of its being raised or lowered, thus throwing the stream on or off the buckets. The power of the wheel is consequently increased or diminished, according to the change of load, and a constant speed is maintained. A steel deflecting plate, which deflects the stream itself, the nozzle remaining stationary, is sometimes used to accomplish the same results when the design will not admit of a deflecting nozzle.



FIG. 9.—Instantaneous photograph of Tangential Wheel fitted with Pelton Buckets when running at high efficiency, showing the discharge from the sides of the buckets parallel with the entering jet; the photograph also shows clearly that the front of the Pelton Bucket enters the stream without shock or disturbance of any kind and that all of the energy is removed from the water by the bucket.

The needle nozzle consists of a nozzle body in which is inserted a concentric tapered needle. A change of position of this needle produces a corresponding change of discharge area of the nozzle. The amount of water used is thus varied and the power of the wheel influenced proportionately.

The needle and deflecting nozzle is a most valuable combination, consisting of a deflecting nozzle, with which is incorporated a needle nozzle with means for operating

either the needle or deflecting nozzle simultaneously or separately. The deflecting nozzle in itself is a most sensitive means of regulation when actuated by an automatic governor, but does not save water. On the other hand, the needle nozzle, while it is extremely economical in the use of water, is difficult to control quickly by means of the governor. The operation of the combination is as follows:

Assuming the full load to be on the water wheel, and the nozzle in position of greatest efficiency, a decrease of load will cause the nozzle to be suddenly deflected by the automatic governor. Simultaneously the needle portion of the nozzle will be actuated by hand, or by another automatic device, tending to gradually close the needle and decrease the flow. The governor then raises the nozzle to accommodate the decreased flow of water (and consequent decrease of power), and the nozzle is then brought back to the position of greatest efficiency, having, at the same time,

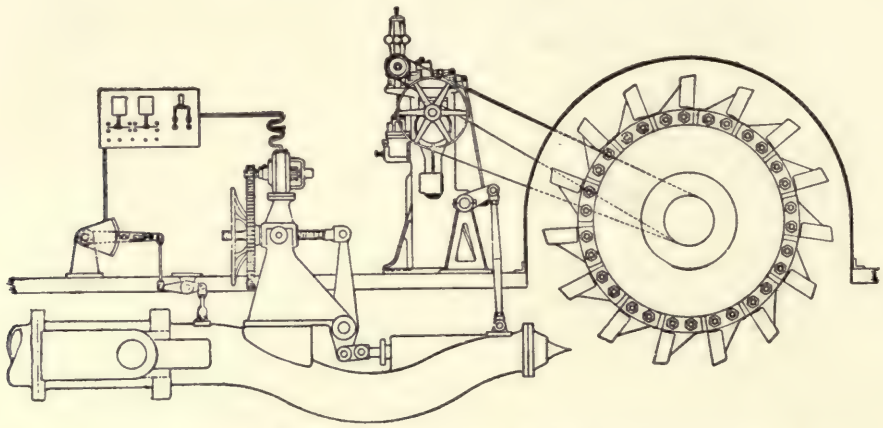


FIG. 10.—Automatic Needle and Deflecting Nozzle, Pelton Impulse Wheel.

controlled the speed within the required limits. Such a device is essential where water is valuable and where economy is necessary to carry over the peak load. The needle portion need not necessarily be operated by an automatic device, but may be controlled by hand, and the same results obtained, although necessarily in a longer period of time. An installation of this combination is given in Fig. 10.

The lower end of penstocks, particularly of high-head plants, must be provided with relief valves, as already discussed under penstocks. Fig. 11 shows a battery of relief valves as employed by the Pelton Water Wheel Company in connection with their impulse wheels. They may be installed either singly or in a battery, which depends on the size of the penstock and the working head. These valves are set to operate at a pressure slightly greater than the normal, and in the event of the water flow being suddenly checked by the closing of the gate or operation of the governors the safety valves momentarily open and relieve the pressure, thus guarding the penstock against the possibility of water hammer.

Accessories. For operating hydraulic governors either by water or oil pressure, additional auxiliaries such as oil pumps, pressure accumulators, and water filters

are necessary. Particular care must be taken, if the penstock water is used in hydraulic governors, to clean same, which is done by sending the water through a screen chamber. There must be at least two screens, so that one may be in use when the other is being cleaned.

The pressure oil for the relays or pilot valves of the governors is usually supplied by motor-driven plunger pumps. As this oil is also used in the step and thrust bearings and frequently must be under high pressure, the pressure to the governor

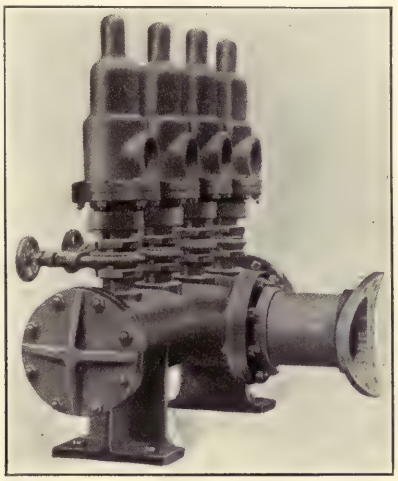


FIG. 11.—Battery of Relief Valves.

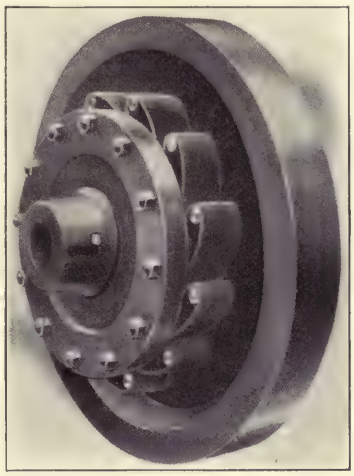


FIG. 12.—Combination of Fly-Wheel and Flexible Leather Link Coupling.

must be lowered by reducing valves. To insure continuity of operation two or more pumps must be installed. In connection with these, accumulators are installed to take up fluctuations in the pressure.

Couplings. The turbines may be rigidly or flexibly coupled to the generators. The rigid coupling is used where there is little fluctuation on either the hydraulic or the electrical end of the plant. The flexible couplings serve two purposes: first, to take up light speed variations; second, in most cases it insulates the turbine from the generator, as the actual connection between the turbine and generator is done by means of leather or rubber. A coupling very much used in Switzerland is the Zodel. It consists of two concentric cylindrical flanges provided with slots, through which a belt is wound in and out. Frequently these couplings are so designed as to act as a fly wheel to balance fluctuations of load. A coupling designed on this principle is shown in Fig. 12.

OILING SYSTEM.

Oil Required. It is of vital importance to install an oiling system in all power plants, large as well as small. A complete oiling system collects the oil from the bearings, filters it and returns it to the machine, all of which is done automatically. From 50 to 70 per cent of oil used in power plants is wasted if means are not provided to collect same.

Filtering Tanks. The filtering tank must be so located that the oil will flow to it by gravity. The tanks must be installed in a fireproof compartment. This

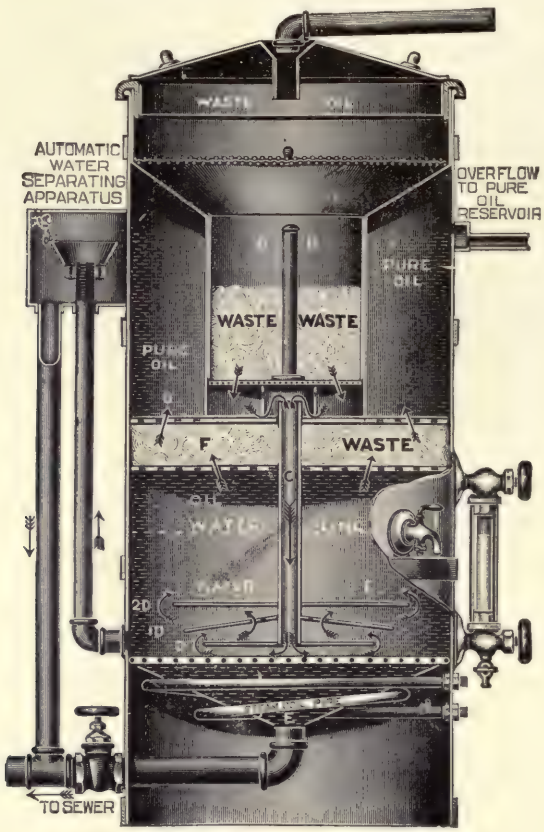


FIG. 1.—Burt Oil Filter.

compartment may also contain the oil pumps as well as the waste cleaner and drier. The door must be so arranged that it will shut automatically. If the room is large, it is better to install two doors, one as a means of easy escape for the attendant. The floor must be provided with proper drainage, as it is frequently necessary to clean the tanks and filters.

Many of the larger power plants have filtering tanks of special design, but common practice is to install some regularly manufactured article. The tanks must be in duplicate, or so arranged in compartments that one may be cleaned at

a time without putting the entire tank out of service. Large tanks may be constructed of many compartments. The oil, entering through cheese cloth or light canvas filters, passes through the compartments at a low velocity, precipitating any foreign substances.

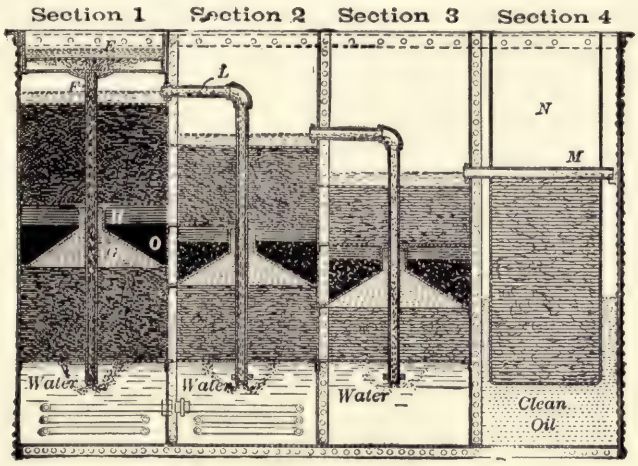


FIG. 2.—Turner Oil Filter.

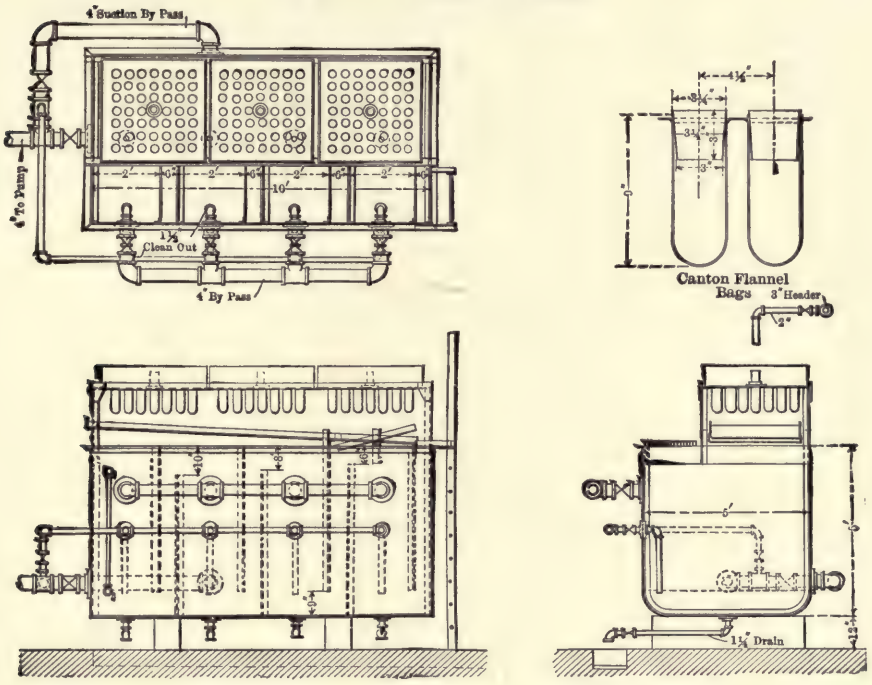


FIG. 3.—Oil Filtering Tank for Large Capacities.

The filtering tanks may have a heating coil to heat the oil, thereby increasing the speed of filtration and causing more rapid precipitation. When, however, high speed turbines are used, and the temperature of the oil returned to the filters is high, the use of the coil may be dispensed with.

Very frequently the oil returned contains a certain amount of water. It is important to abstract this water. Fig. 1 shows a typical oil filter of this type as manufactured by the Burt Manufacturing Company. The oil entering at the top passes through the waste contained in the center chamber, from where it passes downward through the pipe *C*, is heated by the coil and flows upward through the water contained in the lower portion of the tank. This water forces the oil through the waste *F* into the pure oil compartment, from which it is drawn off and reused. The water is discharged to the sewer through the automatic water separator, shown on the left-hand side of the cut.

Another very efficient oil filter is shown in Fig. 2, representing the Turner system. As will be seen, this tank is divided up into four sections. The oil passes through the filtering material of each section, having its temperature raised by coils in the first two sections. A very efficient oil filtering tank is shown in Fig. 3. The tank is divided into chambers by partition walls extending alternately to the top and bottom of the tank, giving the oil an up and down flow, thus increasing precipitation, which will be greater the lower the velocity. The oil before entering the tank passes through Canton flannel bags, arranged in trays as shown in the illustration. These bags are removable, and when dirty, may be replaced by clean ones. The pipe connections are such that any chamber may be separately cleaned without shutting down the entire filter.

Oil Pumps. The pumps required for an oiling system are either high or low pressure. The latter are used with a central oiling system. Duplicate pumps must be installed in order to keep one in reserve. With certain turbines high-pressure pumps are required to pump the oil into the step bearing. It is better practice to install several small-size pumps than one or two large ones, as the possibility of shut-down is thereby lessened. With the vertical turbine in some instances water is used for the step bearing, with practically the same results as those obtained with the use of oil. The entire equipment, with the exception of the filtering tanks, is the same as the oiling system.

Supply Tanks. Frequently it is necessary to install one or two elevated supply tanks, from which the oil is fed by gravity to the various bearings. These tanks must be properly vented, and where more than one tank is employed, they must be interconnected. In order to avoid complicated and long pipe mains, these tanks are preferably placed somewhere in the center of the plant. As the oil is used over and over again, and its temperature is increased each time it is used (especially with high-speed turbines), it might be necessary to cool the oil by means of water coils placed in the supply tank, before it returns to the bearings.

Oil Piping. The return pipes leading the oil from the various bearings or collecting pans to the filtering tank may be of either wrought or cast iron. The former is preferable, however, for small pipes. If wrought iron is employed screw fittings may be used. In order to secure a good gravity flow for the oil the pipes should be pitched at least one inch in every ten feet.

Where many returns are connected to one common header, provision has to be made for the removal of air. This is accomplished by placing one-half inch or

three-quarter inch vent pipes on the header. These vents must extend above the highest point in the return piping, so that, if the pipe discharging to the filter becomes plugged, the oil will not escape through the vents. To facilitate cleaning the pipe, it is good practice to install crosses instead of tees in the header, one leg being plugged. The supply pipes from the filter to the elevated tank, and also the pipe from the tank to the machines, must preferably be made of brass or copper. This is absolutely necessary, as steel, wrought-iron, or cast-iron pipe contains a scale which oil loosens, and if this scale gets into the bearings it is liable to cause considerable damage. Galvanized iron pipe has been tried for supply piping, but experience has shown that the galvanizing will wear off and the pipe will scale as badly as a black iron pipe.

It is essential to keep the pressure constant in high-pressure oiling systems. This may be accomplished by accumulators.

TESTING TURBINES.

European Methods. It is difficult to keep the load and revolutions of a turbine steady for long periods, to secure data for figuring the exact water consumption. It is therefore essential to devise a system whereby the flow of water is indicated simultaneously with the load and revolution of the turbine. This is best accomplished by automatic graphical methods, registering the load, revolutions, water levels in head and tail race, water discharged, and time. A device of this kind (Reichel and Fuess system) is seen in Fig. 1. It has been used for some years in Germany, and consists of a vertically revolving drum, with six different recording indicators for the different readings. The drum, by means of worms and gears, is actuated by a 220 V. $\frac{1}{40}$ HP. motor, making 2750 R.P.M., and the speed of the drum can be varied at will between 0.6 mm. and 15 mm. per second. The drum itself can be set in four different positions on the vertical shaft, so that four complete tests can be recorded on the same sheet.

It will be observed that there is a clock connected with the recording mechanism, cutting in and out the four relays for the four lower indicators. The two upper indicators are attached to the wires running to the floats, one for the headrace and the other for the tailrace.

The load on the turbine is measured by a Prony brake, and indicated on the recording device. The discharge of the tailrace, measured by current meters, is also recorded.

It is usually difficult to measure the exact discharge of the tailrace, as it varies greatly according to the proximity of the channel walls, and, as an exact average flow throughout the channel can hardly be ascertained, because a constant turbine load is only of short duration, therefore it is well to install a number of current meters. This may be done by having three or five meters, according to the depth of the tail-race channel, on a vertical shaft secured to a carriage, which is moved across the channel to four or six points, depending on the width of same.

The carriage must move easily, the rollers resting on an I-beam or channel iron,

so that successive measurements can be taken very rapidly by running the carriage along to different points. Practice shows that by having three current meters on one shaft, and moving the carriage in five different positions, fifteen readings of the tailrace cross section can be made in five minutes.

For measuring the discharge of the turbine in a simpler and perhaps the most accurate way, a method has been long in vogue in Norway and Sweden and recently

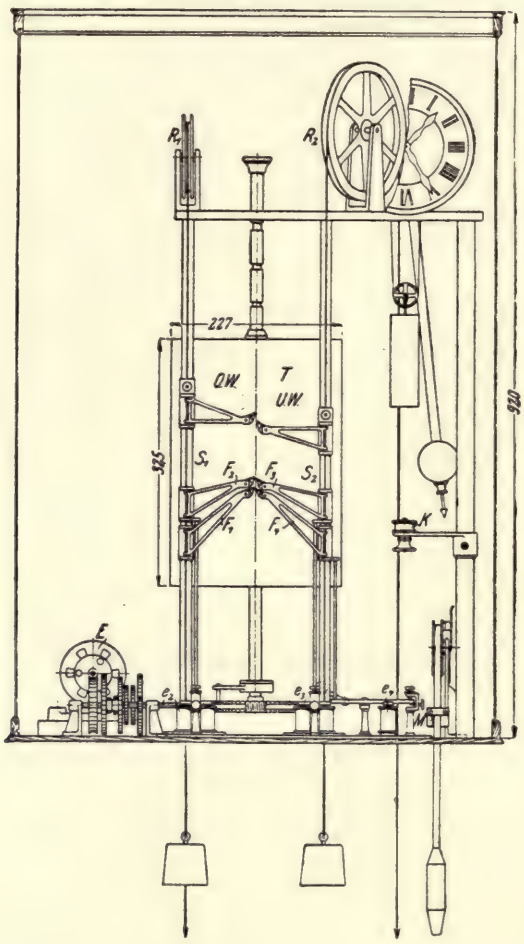


FIG. 1.—Automatic, Graphical Registrator for Testing Turbines.

introduced into Germany. It was developed by Prof. Erik Anderson, Stockholm. To make use of this method, the tailrace must be some 30 feet to 40 feet long and have a uniform cross section with smooth surfaces. A carriage, preferably made of aluminum or light steel bicycle tubes, rests on a smooth track, preferably on the planed legs of angle iron. To the carriage is hinged a light framework of wood or steel, of the width of the tailrace, giving on each side a clearance of about a quarter

to three-eighths of an inch. This frame is covered with oiled cloth or other waterproof canvas. The total weight of those as illustrated in Fig. 2 is about 80 pounds, and takes about 0.8 pound to move same.

Fig. 3 shows the general arrangement of a testing plant at Heidenheim. At point *I* the curtain is lowered and soon assumes a vertical position before entering the area of measurement. Point *III* shows the carriage in a position, with the

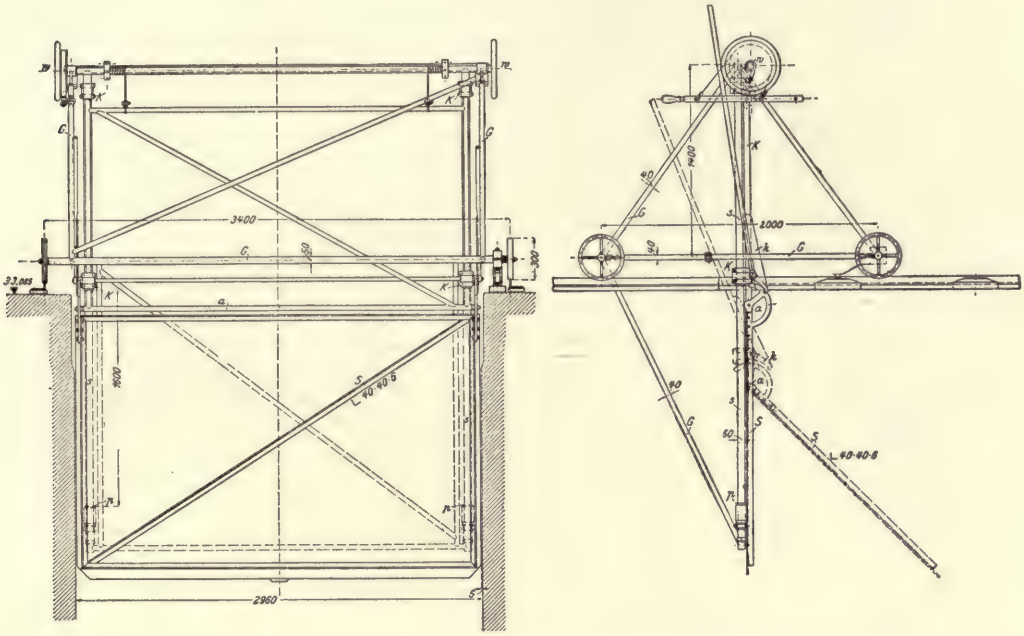


FIG. 2.—Carriage with Curtain for Testing the Water Discharge of Turbines.

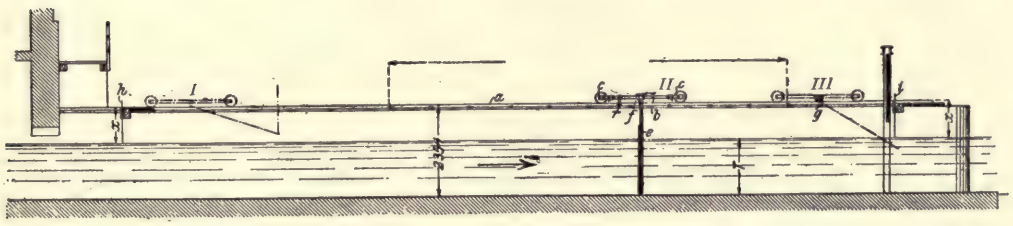
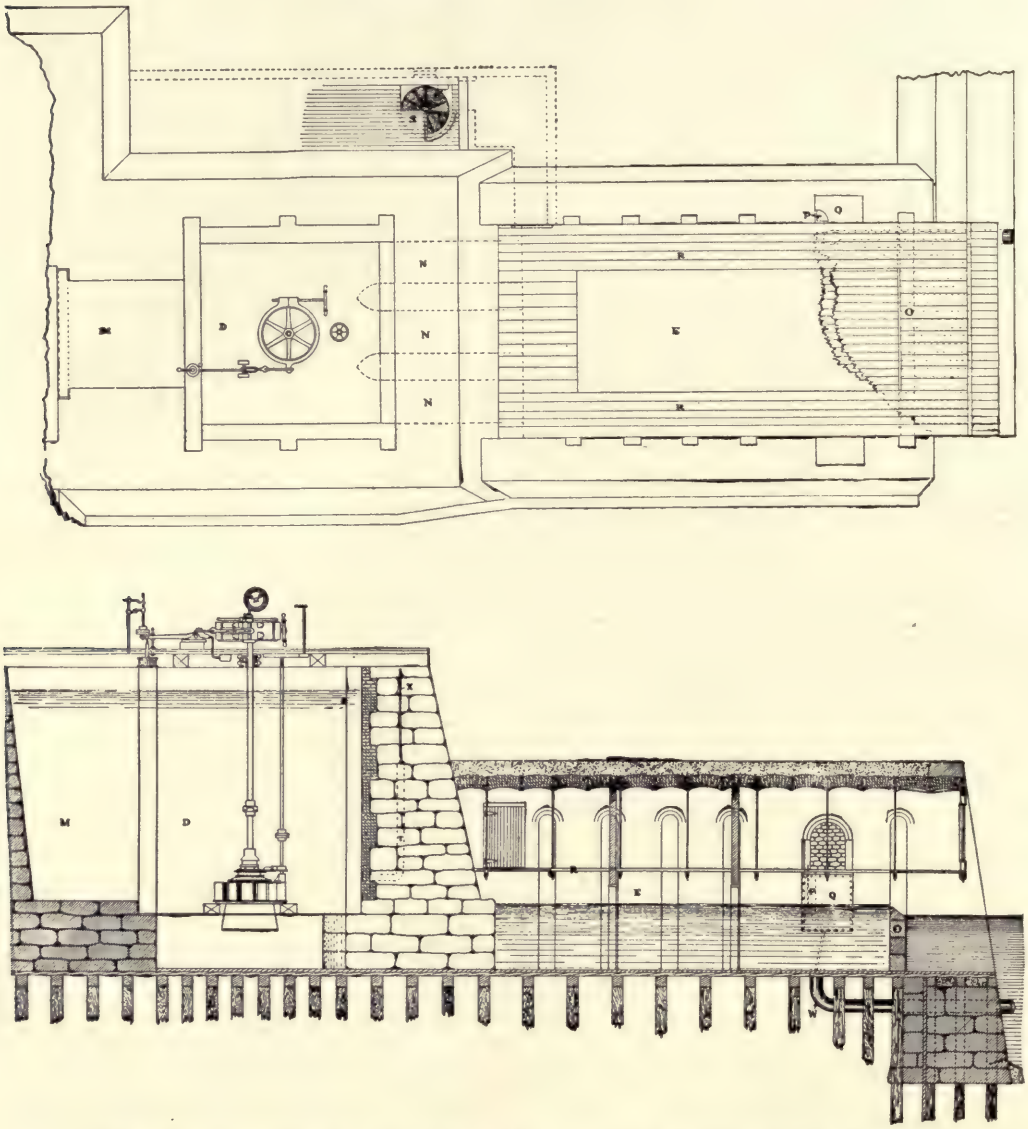


FIG. 3.—Arrangement for Measuring Tailrace Water in Testing Turbine by the Curtain Method.

curtain released from the vertical position by means of a trip device; the carriage is then drawn back for another run. Practice shows that every four minutes a complete test can be recorded. The speed of movement depends on the exact uniform water velocity throughout the tailrace channel. It must here be stated that with a water velocity of less than 0.5 foot per second the measurements become inaccurate. The position and time of travel are recorded by electrical contacts placed some three to five feet apart.

The difference in the water level at both ends of the tailrace varies between one and two millimeters; the average is taken as final. Such tests are not made on windy days, because the outside water is swept into the tailrace, and the force of same is oftentimes sufficient to reverse a current meter.



FIGS. 4 and 5.—Plan and Section of Holyoke Testing Flume, showing Turbine in Position for Test.

Holyoke Tests. Most of the low-head turbines manufactured in America are tested at the flume of the Holyoke Water Power Company, Holyoke, Mass. As the head on this plant is only 18 feet, and is seldom constant, due to great fluctuations, all the readings therefore have to be reduced to a uniform head. Further, as the

conditions of the flume and the setting of the wheel are different from those at the plant where the wheel is to be installed, the value of the Holyoke tests may be judged from the following comparison.

Due to the high efficiency claims of some American manufacturer, a German concern intended to build turbines after the American type, for which purpose it bought a 16-inch turbine, duly tested at Holyoke, then tested in Germany by Professor Pfarr, one of the highest German authorities on turbines. The results of these tests are published in the *Zeitschrift des Vereines deutcher Ingenieure*, June 7, 1902. The comparison of the efficiencies is as follows:

Discharge.....	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3
Holyoke test.....	0.81	0.795	0.765	0.725	0.67	.....	.....	.....
German test.....	0.718	0.703	0.693	0.658	0.591	0.491	0.358	0.121

The discharge is the actual discharge and is not figured on the proportional gate opening. During the Holyoke tests the total weight on the step bearing was 25 per cent greater than that in the German tests.

For these reasons, guarantees of such tests must not be accepted by the power plant designer; he should accept only such guarantees as are made in the power plant itself.

However, as the Holyoke tests are used in many respects as a standard in American practice, a brief description of the Holyoke Test Flume method of testing and deduction as given by the Dayton Globe Iron Works Company is given below.

For the purpose of making the necessary experiments on the wheels, the Holyoke Water Power Company built a permanent testing flume, in which the wheels are tested both for power and for amount of water discharged. They are usually tested at five or six different openings of the gate, ranging from full open to the opening at which the discharge is one-half that at full opening, and at six or eight different velocities of revolution at each gate opening, and making some thirty to fifty experiments on each wheel. The final result is that for all practical purposes the water wheel is converted into a water meter, and its discharge may be known under any of the conditions under which it will have to run. Besides this, its efficiency or value as a motor is also known.

The essential portion of the testing flume consists, in the main, of the trunk or penstock *M*, bringing the water into the wheelpit *D* and the tailrace *E*. In the passageway *M* are placed two sets of racks, or baffleboards, to stop eddies and oscillations in the flowing water. Baffleboards are also placed in the tailrace for the same purpose. Flume wheels are set in the center of the floor of *D*, and *D* is filled with water. They discharge through the floor of *D* and out of the three culverts *N*, *N*, *N* into the tailrace *E*. At the downstream end of this tailrace is the measuring weir *O*, the crest being formed of a piece of planed wrought iron. It can be used with or without end contractions. The depth of water on the weir is measured by a hook gauge, in a cylinder *P*, set in a recess *Q* fashioned into the sides of the tailrace. These recesses are water tight, and the observer is thus enabled to stand with the water level about breast high, or at a convenient height for accurate observation. The methods of measuring water over this weir are those described in Lowell Hydraulic Experiments, by James B. Francis.

A platform *R* surrounds the tailrace, and is suspended from the iron beams that roof it in. The wheels to be tested are lifted from the wagon or cars by a traveling windlass, and run into the building

and lowered into the wheel pit *D*. Winding stairs *S* lead into a passageway that leads in turn to the platform *R*. In the well hole of these stairs is set up the glass tube *X*, which measures the head of water upon the wheel. It is connected with the pit *D* by means of pipe running through a cast-iron pipe *T*, built into the masonry dam which forms the downstream end of the wheel pit *D*. The power is weighed by a Prony brake, consisting of a cast-iron pulley surrounded by a wood-lined jacket, cooled and lubricated by water from the city mains, or, if necessary, with the addition of a small stream of soap-water. The pull of the jacket is weighed by a bent lever and weights, the friction being regulated by an attendant at the temper screw, so that the weights are kept balanced. To enable the observer at the brake wheel, the one at the head gauge and the one at the measuring weir, to take simultaneous observations at intervals of one minute, an electric clock is set up, which rings three bells simultaneously at intervals of one minute, or of half a minute if desired. The whole structure is built in a durable and efficient manner. The pits and tailrace are all lined with brick laid in cement. The stone masonry was intended, by careful work and grouting, to be water tight without the brick lining, and the brick lining was then carefully laid up with joints full of mortar, as an extra precaution. As a consequence, the front of the wall forming the downstream side of the pit *D* is built so tight that an exact measurement of the leakage of the wheel gate could be made if desired. An approximate estimate is readily made by filling the pit before the tailrace is allowed to fill up and apportioning the total measured leakage of the wheelgate and that of the flume.

W shows a waste pipe. Another not shown serves to draw the water out of and through the floor of the pit *D*. To close or open these waste pipes they are fitted with cases of small water wheels, which thus form convenient valves for the purpose indicated.

The pipe *W* leads into a sewer on the other side of the second level canal and thence into the river. It enables the tailrace to be emptied of water down to within some three inches of the bottom planking. After the wheel to be tested is placed in the flume, and the dynamometer placed on the shaft, the lever is adjusted, care being taken that it is horizontal and tangent to the circumference of the brake at point of application of the pull. It is balanced by placing a small weight first on one side and then on the other of the fulcrum, and at equal distances from it, and noting the time necessary to move the long arm a certain distance above and below the center, and then adjustment of the counterpoise until the times become equal. A dashpot is always used with the lever to steady its oscillations.

An indicator is attached to the turbine gate or to the mechanism controlling it, so that the position of the gate is always known.

The hook gauge is set by an engineer's level so that point of hook is level with crest of weir when scale on the gauge reads zero. The length of the weir is adjusted to the proper length for the quantity of water to be measured. The floating gauge, by which head on wheel is measured, is adjusted so that the zero of its scale is at the level of tail water.

In the system followed there are three observers, each taking a reading of his gauge every minute and keeping a separate set of notes. The notes from which the theoretical or gross power of the water is computed are kept by the men at the head gauge and hook gauge, and consist of a simple measurement of the head, or vertical distance from surface of water in flume over the wheel to surface of tail water, the length of the measuring weir, the number of its end contractions, depth of water flowing over the weir, and temperature of water.

All data for the effective power of the wheel are taken by the third observer, and consist of the circumference of the brake at point of application of the weight, ratio of the lever arms, number of pounds on the lever, revolutions of the wheel per minute, and setting of the wheelgate.

Of the data, all excepting setting of the gate, weight on lever, revolutions, head and depth on the weir, are generally constant throughout one wheel test.

The variable data are compared with each other, and for any one experiment consecutive readings are selected where everything goes to show that revolutions, head, and depth on the weir are steady and consistent with each other. These readings in each notebook are then averaged, and these averages compose the variable data for the experiments, a full set for each change of weight on the lever.

The quantity of water passing the weir is computed by the Francis formula:

$Q = 3.33\ (L - .1\ nh)\ h^{\frac{3}{2}}$, in which
Q = quantity in cubic feet per second.
L = length of weir in feet.
n = number of end contractions.
h = depth on the weir.

If the volume of water renders it necessary, Q is corrected for velocity of approach.

Q is then diminished by the leak of flume floor, and result is the net quantity of water passing the wheel.

Theoretical power of water in horsepower is

$$\text{HP. (water)} = \frac{q \times H \times 60 \times Wt}{33{,}000},$$

in which q = cubic feet per second passing the wheel.

H = head on wheel, in feet.
Wt = weight in pounds of one cubic foot of water, according to temperature.

Effective power of wheel is

$$\text{HP. (wheel)} = \frac{W \times R \times l \times c}{33{,}000},$$

in which W = weight in pounds on lever-arm.

R = revolutions per minute.
l = ratio of lever-arms.
c = circumference of brake.

$$\text{Efficiency of wheel} = \frac{\text{HP. (wheel)}}{\text{HP. (water)}}.$$

On account of fluctuations in height of the canal from which water is drawn for testing, and on account of varying depth of water over the weir, the head on wheel is not constant throughout the test, so that the discharges at various gates and speeds cannot be directly compared, but must first be reduced to a uniform head, H', by the rule

$$q' = q \sqrt{\frac{H'}{H}}.$$

The discharge at full gate and at the speed of revolution giving the maximum efficiency, is taken as the unit discharge, and the discharge (q') of each experiment is divided by it so that in the final report, the column of " proportional discharge " shows the percentage of water used in each experiment.

Deductions from Tests. Having given above a description of how a test is made, the horsepower, speed and amount of water discharged by the same wheel under any head is deduced. This is done in the first place, to enable any one who so desires to determine for himself whether a wheel that has been tested and the test made known has been correctly tabled as to its horsepower, speed and amount of water discharged, or, in other words, whether such table has been actually deduced from such test; in the second place, to show that a wheel that has not been tested cannot be correctly or reliably tabled as to its horsepower, speed and discharge, as the data required for these deductions can only be obtained by means of a test. To illustrate, the theoretical discharge of a wheel under a given head can be ascertained by measuring the cross section or area of its discharging openings and multiplying same by the theoretical velocity of the water under the given head, but the actual discharge can only be ascer-

tained by measurement, over a weir, of the amount of water actually discharged by the wheel when in operation. The ratio of the actual discharge to the theoretical discharge is called the coefficient of discharge.

The discharge being known, the theoretical power of the water can be ascertained by computation by formula given above, but the actual power of the wheel can only be ascertained by measurement with a dynamometer or other appliance. The ratio of actual power developed to the theoretical power is the efficiency of the wheel.

The speed of a wheel of given diameter under a given head is due to the velocity of water under that head, and the ratio of the actual to the theoretical speed is the coefficient of speed or relative velocity. Without these three coefficients it is impossible to table a wheel as to power, speed and discharge.

Any tables of power without an accompanying test to show how same have been deduced should be condemned, and any tables of power accompanied by test should be carefully examined to ascertain whether same have been correctly deduced. Such a course will save the purchaser the expenditure of money and avoid future trouble.

The potential energy of a mass of water is its weight multiplied by the distance it has to fall. This product of the weight into the head gives the work the water performs in foot-pounds. Thus 1000 cubic feet of water weigh 62,333 pounds, and falling 10 feet develops 623,330 foot-pounds of energy, and dividing by 33,000 gives the horsepower. The horsepower a turbine will develop from this quantity of water depends upon the efficiency of the wheel as ascertained by test.

The quantity of water (say in cubic feet per second) which will discharge (theoretically) through an aperture under a given head is ascertained by multiplying the area of the aperture in square feet by the velocity of the water in feet per second due that head, and the area of the aperture remaining the same, the quantity discharged under different heads varies as the velocity. So the quantity under any head being known, the quantity under any other head may be ascertained by the proportion $Q : Q' :: V : V'$, or $Q' = \frac{QV'}{V}$. In the same way the quantity of water discharging through a turbine under different heads varies as the velocity.

Having by test measured the quantity of water discharged by the turbine, and also the head, the discharge under any other head is obtained by the above formula and entered in the table.

Having thus ascertained the discharge in cubic feet per minute for any head, the horsepower is obtained by multiplying the quantity by $62\frac{1}{2}$ (the weight of a cubic foot of water), this product by the head in feet, and dividing the result by 33,000 and multiplying by the per cent of useful effect, or by the formula (2) $\text{HP.} = \frac{Q \times 62\frac{1}{2} \times H}{33{,}000} \times \%$ efficiency. The per cent of efficiency is obtained by dividing the actual by the theoretical horsepower.

It will be seen in formula (2) that the horsepower varies as the quantity and the head, the other elements of the formula remaining constant. Therefore the horsepower varies as the velocity and the head, and the horsepower under any other head can be ascertained by the proportion

$$HP : HP' :: V \times H : V' \times H', \text{ or the formula (3) } HP' = \frac{HP \times V' \times H'}{V \times H}.$$

The speed of a wheel is due to the velocity of the water which drives it. For example, the velocity of water due to fourteen feet head is thirty feet per second, or 1800 feet per minute.

A wheel three feet in circumference, therefore, would make 600 turns per minute. This would be the theoretical speed of the wheel without regard to contracted discharge. The actual speed is taken during the test by an indicator, and the relative velocity ascertained. It follows, therefore, that the revolutions vary as the velocity; the revolutions under any other head may be ascertained by the proportion, $R : R' :: V : V'$, or the formula (4)

$$R' = \frac{R \times V'}{V}.$$

BIBLIOGRAPHY.

MODERN TURBINE PRACTICE. John Wolf Thurso. 1905. Van Nostrand. New York.

HYDRAULIC MOTORS. Irving P. Church. 1905. Wiley & Sons. New York.

HYDRAULIC POWER AND ENGINEERING. G. Croiden Marks. 1900. Van Nostrand. New York.

WATER POWER ENGINEERING. Daniel W. Mead. 1908. McGraw Company. New York.

DIE THEORIE DER WASSERTURBINENEN. Rudolf Escher. Julius Springer. Berlin.

DIE TURBINEN FÜR WASSERKRAFTBETRIEB. A. Pfarr. 1906. Julius Springer. Berlin.

TURBINEN UND TURBINENANLAGEN. Viktor Gelpke. 1907. Julius Springer. Berlin.

NEUERE TURBINENANLAGEN. Wilhelm Wagenbach. 1905. Julius Springer. Berlin.

DIE AUTOMATISCHE REGULIERUNG DER TURBINEN. Walther Bauerfeld. 1906. Julius Springer. Berlin.

WASSERKRAFTMASCHINEN. L. Quantz. 1906. Julius Springer. Berlin.

THE NEED OF TURBINE STANDARDS OF MEASUREMENT. M. A. Reployle. *Engineering News*, Oct. 23, 1902.

MODERN TURBINE PRACTICE AND THE DEVELOPMENT OF WATER WHEELS. John Wolf Thurso. *Engineering News*, Dec. 4, 1902.

TURBINES AND THE EFFECTIVE UTILIZATION OF WATERPOWER. Alex Rea. *Mechanical Engineer*, March 22, 1902.

EFFECT OF DRAFT TUBES. John Wolf Thurso. *Engineering News*, vol. 1, p. 29. 1903.

TANGENTIAL WATER WHEEL BUCKETS. *The Engineer*, May 1, 1904.

NOTES ON THE PURCHASE AND USE OF HYDRAULIC TURBINES. W. Kennely, Jr. *Canadian Society of Civil Engineers*, Bulletin No. 2, December, 1907.

HYDRAULIC TURBINE PRACTICE. Frank Koester. *Practical Engineer*. April, May, 1909.

THE THEORY OF IMPULSE WHEELS. Kingsford. *Engineering News*, July 21, 1898.

REPORT OF A TURBINE TEST. Webber. *Engineering News*, April 20, 1903.

THE GOVERNING OF IMPULSE WHEELS. I. P. Church. *Engineering Record*, Feb. 25, 1905.

NOTES ON GOVERNING HYDRAULIC TURBINES. R. S. Ball. *Engineering*, Aug. 23, 1907.

A NEW METHOD OF TURBINE CONTROL. Lamar Lyndon. *A. I. E. E.*, May, 1906.

SOME STEPPING STONES IN THE DEVELOPMENT OF A MODERN WATER WHEEL GOVERNOR. Mark A. Replogle. *A. S. M. E.*, May, 1906.

ELEMENTS OF DESIGN FAVORABLE TO SPEED REGULATION IN PLANTS DRIVEN BY WATER POWER. Allen V. Garratt. *A. I. E. E.*, June 27, 1899.

SPEED REGULATION OF HIGH HEAD WATER WHEELS. H. E. Warren. *Technology Quarterly*, June, 1907.

A NEW METHOD OF GOVERNING WATER WHEELS. *Sibley Journal of Engineering*, March, 1896.

GOVERNING OF WATER POWER UNDER VARIABLE LOADS. *A. S. C. E.*, June, 1897.

WATER WHEEL REGULATION. Samuel N. Knight. *Journal of Electricity*, November, 1897.

MODERN PRACTICE OF WATER WHEEL OPERATION. *Electrical World*, May 5, 1900.

COMMERCIAL REQUIREMENTS OF WATERPOWER GOVERNING. Elmer F. Cassel. *Engineering Magazine*, September, 1900.

A WATER WHEEL GOVERNOR OF NOVEL CONSTRUCTION. *Engineering News*, Nov. 13, 1902.

SPEED REGULATION IN WATERPOWER PLANTS. J. W. Thurso. *Engineering News*, 1903, vol. 1, p. 27.

THE GOVERNING OF IMPULSE WHEELS. John Goodman. *Engineering*, Nov. 4, 1904.

THE REGULATION OF HIGH PRESSURE WATER WHEELS FOR POWER TRANSMISSION PLANTS. George J. Henry, Jr. *A. S. M. E.*, May, 1906.

TURBINE DESIGN AS MODIFIED FOR CLOSE REGULATION. George O. Buvinger. *A. S. M. E.*, May, 1906.

SURGE TANKS FOR WATERPOWER PLANTS. R. D. Johnson. *A. S. M. E.*, 1908.

THE GLOCKER-WHITE TURBINE GOVERNOR. W. M. White and L. F. Moody. *Power*, 4, 1908.

THE EFFICIENCY OF WATER WHEELS. F. M. F. Cazin. *Electrical World*, Jan. 9, 1897.
IMPULSE WATER WHEEL EXPERIMENTS. E. A. Hitchcock. *Electrical World*, June 5, 1897.
SYSTEMATIC TESTING OF TURBINE WATER WHEELS IN THE UNITED STATES. R. H. Thurston. *Am. Soc. M. E.*, 1897, p. 359.
TANGENTIAL WATER WHEEL EFFICIENCIES. G. J. Henry, Jr. *Am. Inst. E. E.*, Sept. 25, 1903.
EXPERIMENTS AND FORMULA FOR THE EFFICIENCY OF TANGENTIAL WATER WHEELS. B. F. Groat. *Engineering News*, 1904, vol. 2, p. 430
EFFICIENCY TESTS OF TURBINE WATER WHEELS. Wm. O. Webber. *Am. Soc. M. E.*, May, 1906.

A.E.&M.
UNIV. OF CA

CHAPTER VII.

ELECTRICAL EQUIPMENT.

GENERATORS.

Classification. In modern high-tension transmission systems, alternating current generators are practically exclusively used. They are wound either for single, two or three phase, and connected either in star or delta. The choice of any of the three systems depends on the character of the transmission system. The generators are classified as inductor, revolving armature and revolving field type.

Inductor Generator. This type of generator derives its name from the projecting ends of the rotating element which are termed inductors. The chief advantage of this generator is that there is no rotating winding, as both field and armature wires are stationary. The rotating element is nothing but a mass of iron, consisting of a cast spider made in two or more parts, depending on the size.

The rim of the spider is provided with lugs, to which the laminated pole pieces are fastened. Due to the simple construction of the revolving element, high peripheral speed may be attained without setting up excessive stresses.

As seen in Fig. 1, the field coil is stationary and clamped in the middle of the machine. Its winding consists of copper wire or strips, properly insulated and well ventilated. As it is not necessary to surround each individual pole piece on all four sides with copper winding, the amount of copper used in winding these field coils is less than that in revolving field generators.

The armature winding usually employed is what is called the "concentrated winding," that is, there is only one slot per phase per pole. The percentage of space taken up by the insulation in this style of winding is less than that in the "distributed winding," consequently more space is left for copper conductors, a factor which is of special importance in high-voltage machines. They are wound for 2300 or 6600 volts, and usually are of the two or three phase type.

The pressure wave of an induction alternator can be made to closely approach a pure sine curve, a factor of great importance in long-distance lines, and also in connection with arc lamps.

The efficiency for both full and partial load is high, which is partly due to the fact that the magnetization of the iron is never reversed, but merely increases from zero to maximum value and then decreasing to zero; if the iron is worked at ordinary densities, the iron losses are small. As a rule, the regulation of inductor alternators is not as close as that of the revolving field type.

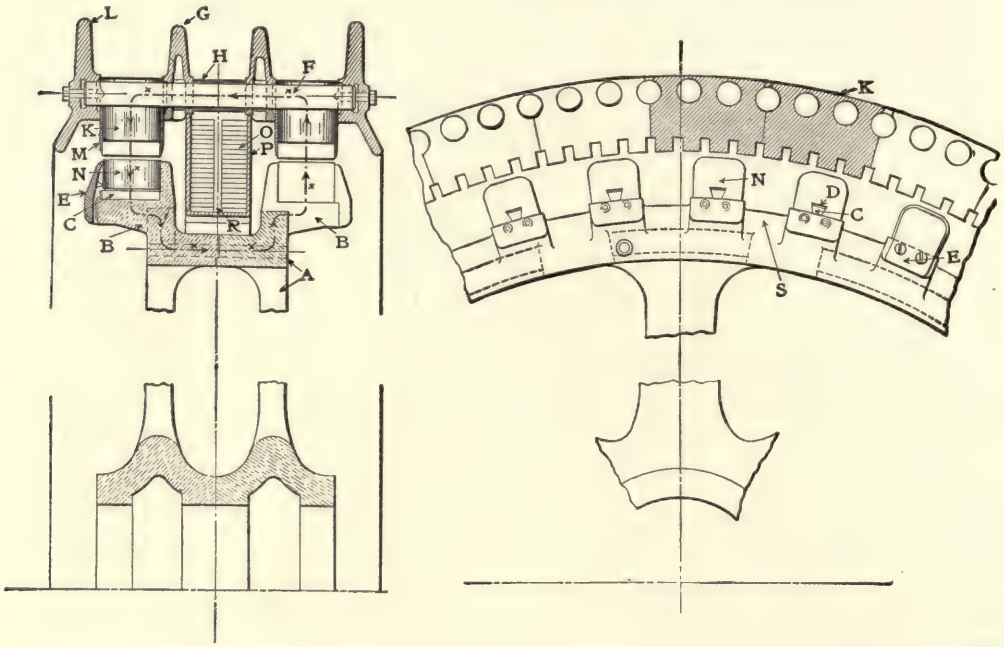


FIG. 1.—Sections of an Induction Generator, General Electric Company.

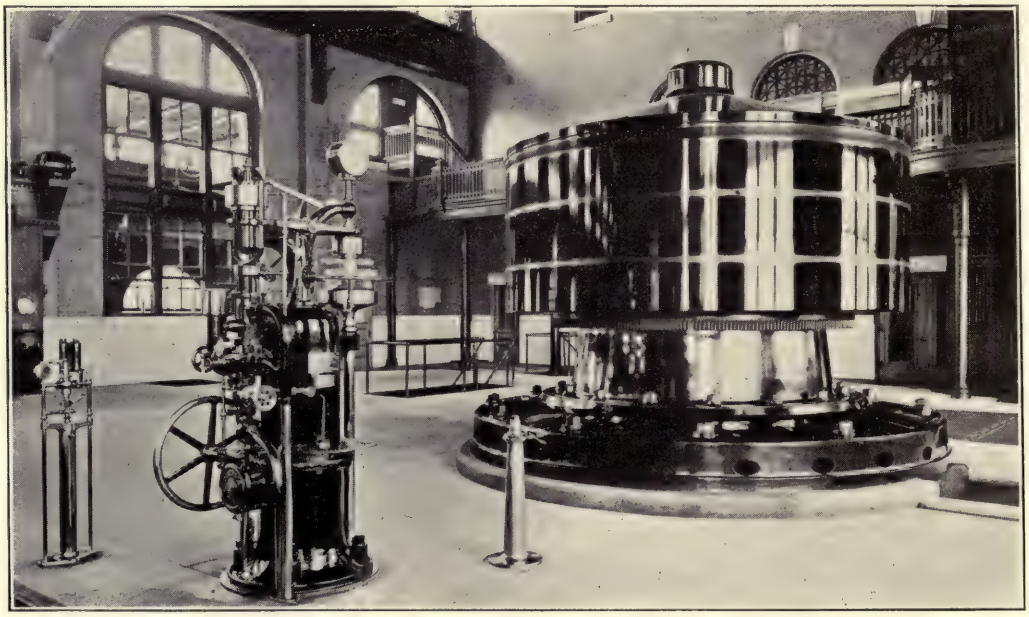


FIG. 2.—5000-HP., 220-volt, Umbrella type, 2-phase Alternator with Internal Stationary Armature, Niagara Falls Power Company, Plant No. 2.

Revolving Armature Generator. The armature in this type of alternator consists of laminated steel rings, mounted on the cast-iron rim of a wheel. The armature ring is built up of thin sheet steel punched in such a way, that when assembled, the completed armature core is pierced with slots for the reception of the winding; ventilating spaces are provided at intervals, as the armature is assembled.

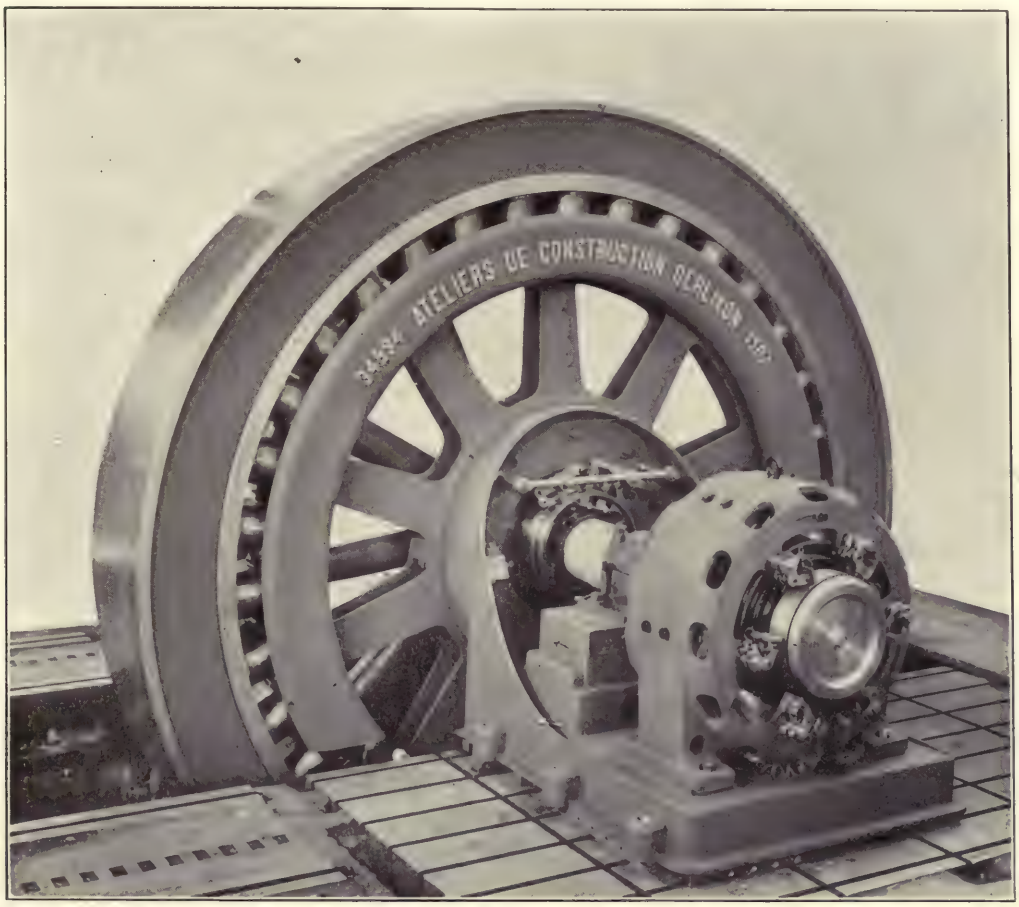


FIG. 3.—225-K.W., 400-volt, 50-cycle, 3-phase, Flywheel Alternator, with Internal Stationary Armature, and Exciter.

According to the amount of current to be carried, the winding consists of wire, straps or bars. For high-voltage alternators of small current capacity, wire winding, in machine wound coils, is used. For low voltage and large current capacity strap wound windings are employed. Copper bars are used where the current in the armature is very high.

The fields of large alternators are made in two or more pieces, the division being vertical or horizontal, so that the frame may be removed and the armature winding is easily accessible. The field poles are made up of thin annealed steel plates and are bolted into the field yoke.

In small alternators, the field coils are made of wire instead of straps, used in large alternators. When strap winding is used, the strap is wound on edge. This type of alternator is not used to any extent for high-tension transmission; its field is confined to isolated or similar power plants.

Revolving Field Alternator. As classified by the name, in this type of alternator, the field revolves while the armature is stationary. This method of construction facilitates the insulation of the armature winding and requires that field current instead of the armature current shall pass through the collector rings and brushes. Due to this, alternators of this type are specially adapted for high voltages for large current output.

The revolving element or field consists of a wheel, upon the rim of which are mounted laminated plates, bolted together; at intervals are air spaces for ventilation. As these pole pieces are built on the circumference of the rim, the revolving element frequently serves the purpose of a flywheel, particularly in connection with low-head turbine plants where the speed is low.

The field coils, according to the size of generator, are either of wire or copper strap wound on edge. When placed in position on the frame, they are securely held by wedges.

The armature winding is stationary and usually external to the field (armature internal to the field and stationary is seen in Fig. 2) and carried in the frame of the machine. The winding is similar to that of the revolving armature type. The stationary parts for small machines are made in one piece, and so arranged that the whole frame can be shifted for inspection. In large machines the frame is split up into sections for inspection and repair purposes.

Regulation. According to the standardization committee of the American Institute of Electrical Engineers, the regulation of an apparatus intended for the generation of a potential, current, speed, etc., varying in a definite manner between full and no load, is to be measured by the maximum variation of potential, current, speed and so forth, from the satisfied condition under such constant conditions of operation as give the required full load values. The regulation of an alternator is the percentage rise in voltage obtained by throwing off the entire non-inductive full load. The speed and excitation of course are constant. Good machines have a regulation of 6 per cent on non-inductive loads and 8 per cent on inductive loads with a power factor of 0.85.

Where synchronous machines are connected to the transmission line, close regulation of the generators is very essential. As these machines run in synchronism with the generator, any sudden variation in generator voltage is transmitted to the synchronous apparatus, which cannot respond owing to the inertia effect of the rotating element. If the changes are very sudden, the synchronous machines will fall out of step and eventually stop. For slight changes, the speed of the synchronous machine will try to keep step with the generator. This action is known as "hunting."

Where the alternator is subject to much fluctuation in voltage, an automatic regulator facilitates the regulation of the machine, that is, it automatically controls

the exciter current to give nearly constant voltage at the generator terminals. It has this advantage: it is independent of the inherent regulation of the machine itself and gives superior results. As an alternator with high regulation is expensive, it is often cheaper to install an automatic regulator on a machine with inferior regulation. The Tirrell Regulator is used on constant-potential circuits and the Thury on constant-current.



FIG. 4.—Eleven 1200-HP., 8000-volt, 50-cycle, 66-R.P.M., 3-phase, Brown, Boveri Alternators. In Front two 400-HP. Exciters, Beznau Plant, Switzerland.

Efficiency. The efficiency of a generator is the ratio of the power output to the power input and is expressed in per cent. Some of the best machines have an efficiency as high as 98 per cent. However, average efficiencies are in the neighborhood of 96 per cent. As the efficiency of a generator depends exclusively on the design and workmanship, it is the best policy for the manufacturer to produce a machine of highest efficiency, and the power plant designer must not hesitate to use same. The efficiencies must be high, not only on a full load, but correspondingly high on fractional loads.

It is the practice, particularly in plants supplying power for railroad purposes, to operate the generators at 50 per cent overload. The highest efficiency is usually attained at 25 per cent overload. This indicates that the generator is designed for greater capacity than actually rated by the manufacturer. European manufacturers

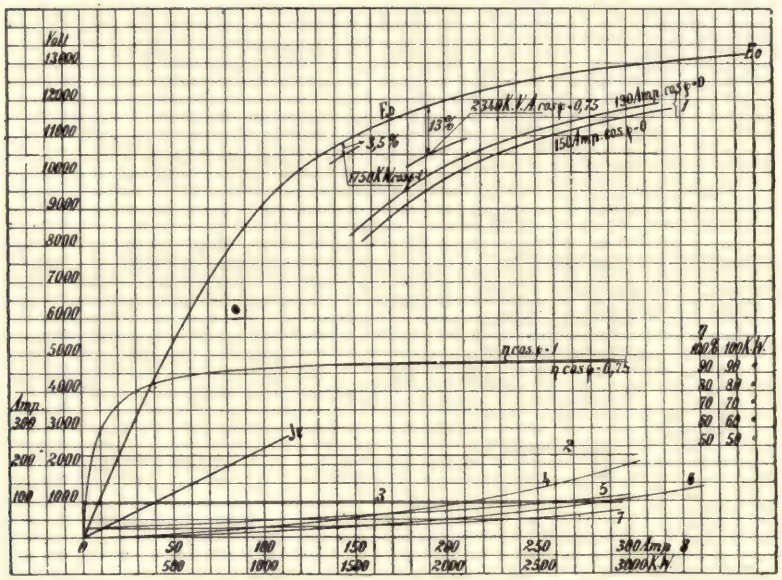


FIG. 5.—Characteristic Curves of 2750-K.V.A. Generator. 9000–10,500 volts, 150 amperes, 42 cycles.

E_0 = No-load characteristic.
J_c = Short circuit characteristic.
n = Efficiency.
2 = Iron loss.
3 = Friction and Windage loss.
4 = Armature copper loss at cos ϕ = 0.75.
5 = Exciter loss at cos ϕ = 0.75.
6 = Armature copper loss at cos ϕ = 1.00.
7 = Exciter loss at cos ϕ = 1.00.

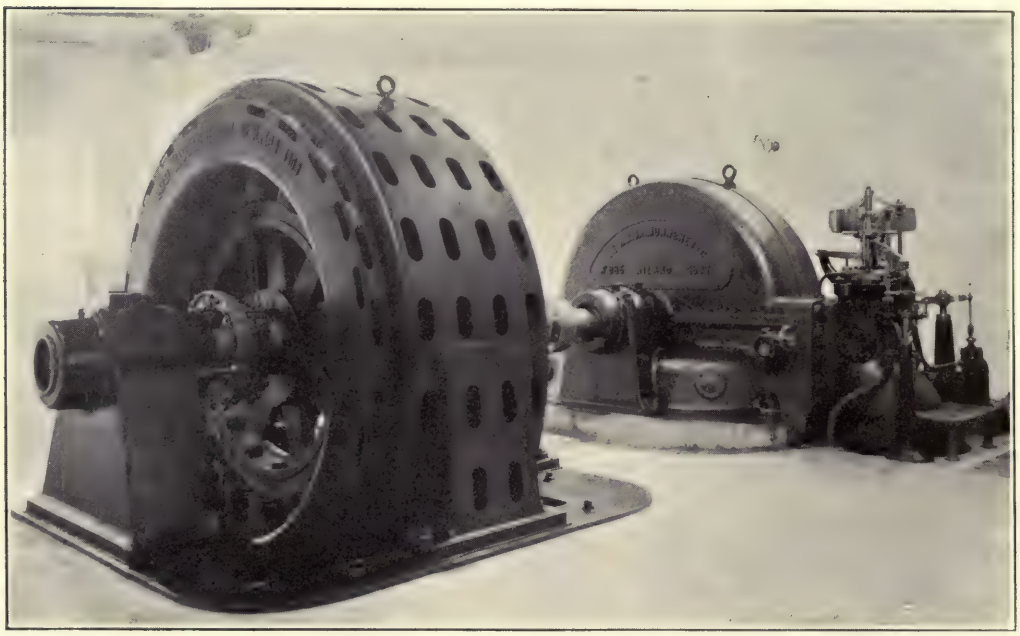


FIG. 6.—2750-K.V.A., 9000–10,500-volts, 42-cycle, 315-R.P.M., 3-phase Alternator (Oerlikon) connected to an Impulse Wheel, Caffaro Plant, Italy.

rate their machines according to the capacity at highest efficiencies, and the overload capacity is usually 25 per cent. When these concerns sell their machines to foreign countries, where 50 per cent overload capacity is required, they follow the practice in America, that is, they underrate the generator. Fig. 5 shows the charactistic curves of a 2750-K.V.A. generator, which is given in Fig. 6. When generators continuously run for 24 hours, the temperature rise of any part of the machine must not exceed from 40 to 45° C. for normal load with a power factor of 0.90 to 1.00. With the same power factor the rise in temperature on 25 per cent overload must not exceed 50° C., and with 50 per cent overload for one hour the rise must not exceed 60° C. above that of the surrounding temperature.

Frequencies. The most common frequencies used are 25 and 60, and depend chiefly on the character of service; 25 is used for power purposes and 60 for lighting. However, there are exceptions where the reverse is true. The lower frequency is chosen because the iron losses in the generators are less and consequently the machine is cheaper. The higher frequency is used for lighting, as it does away with fluctuation. Synchronous machines, such as rotary converters, give much trouble on 60-cycle lines, and in their stead motor-generator sets are substituted, as will be seen in chapter on Substations.

In the last few years 15 cycles have been used for railroading, particularly in connection with single phase, and it is still being discussed in the technical press whether or not it should be adopted as a standard.[1] The principal arguments in favor of 15 cycles are given as :

1. An increase of from 30 to 40 per cent in the output of a motor of a given size, and a consequent reduction in the total number of motors required to operate a railway, and in the cost of equipment.
2. Better performance of the 15-cycle motors, including higher efficiency, higher power factor, and better commutation.
3. Less dead weight to be carried on cars and locomotives.
4. Lower line losses.

In other countries the choice of frequencies varies greatly; for instance, one will find frequencies of 15, 25, 32.5, 42, 60, etc.

Voltage. For low-tension distribution, voltages of 110, 220, and 440 may be considered as standard. For higher generator voltages, 1100, 2200, 3300, 6600, 11,000, and 12,000 are most frequently used in American practice. The choice of voltage depends chiefly on the system of distribution, particularly for long-distance transmission. When the bulk of the power is used in the vicinity, the voltage of the generator must be chosen to suit the most economical distribution, that is, to reduce the use of transformers to a minimum. When the power is transmitted over a long distance, one of the above generator voltages is used and stepped up to a suitable transmission voltage.

Exciters. The exciters are driven either by a separate turbine or from the shaft of the main unit. In the latter case each generator has its own exciter and is

[1] Twenty-five versus Fifteen Cycles for Heavy Railways, by N. W. Storer. Am. Inst. E. E., July, 1907.



FIG. 7.—Interior of Submerged Power Plant of the Patapsco Electric and Manufacturing Company. 300-K.W., 3-phase, 60-cycle, 11,000-volt Allis-Chalmers Alternators, running 240 R.P.M.

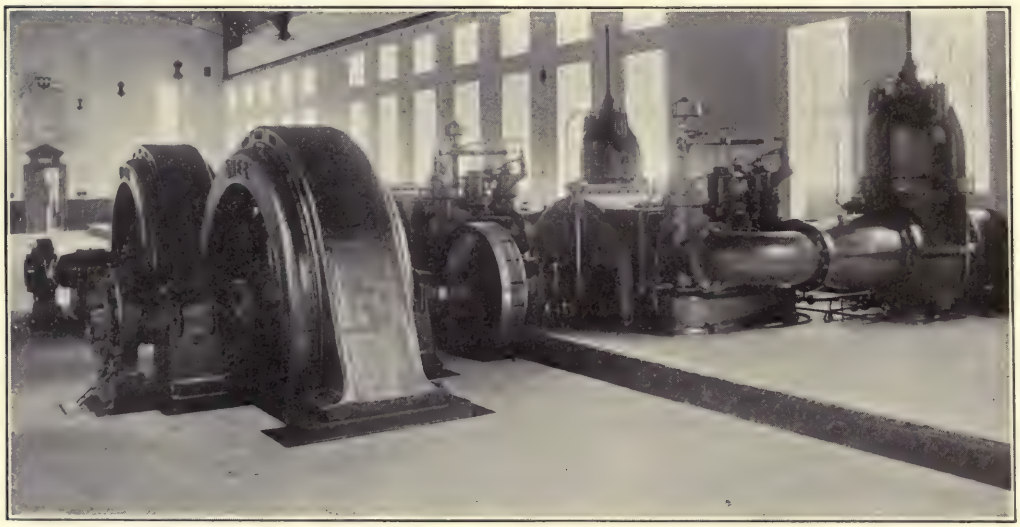


FIG. 8.—Interior of Sill Plant, Insbruck, Tyrol. Each Unit consists of two Impulse Wheels, Zodel Coupling, and a 2000-K.W., 10,000-volt Generator with Overhanging Exciter.

seldom belt-driven, but is mounted on the overhanging shaft of the generator; it is therefore dependent on the operation of the main unit, the disadvantage being, in case the speed of the main unit should drop the excitation diminishes, thus necessitating the installation of an automatic regulator. With a turbine-driven exciter the excitation of the generator is independent of its speed.

The exciter has the same type of turbine as the main unit. Lighting of the station is frequently supplied by the exciter units. The voltage of the exciters depends much on the voltage used for lighting purposes, also for operating plant auxiliaries.

In connection with the exciters, storage batteries are installed which float on the exciter busses to take care of fluctuations and peak loads. This is particularly true where the exciters are mounted on the main generator shaft. Current may be drawn from the storage batteries for operating the high-tension oil switches. When the turbine-driven exciter is employed there must be more than one, to take care of emergency cases. In small or average-size plants the exciter is of sufficient capacity to excite all of the generators at once, while the second unit is kept in reserve. In plants above say 50,000 K.W. capacity it is good policy to install several exciter units instead of two. These are so connected that they feed one common bus from which the main units are excited. The size of the exciters is from one-half to one per cent of the output of the plant, and as reserve must be provided, the combined capacity is about two per cent of that of the plant. The voltage usually employed for American or British practice is either 125 or 250 volts.

Generator Leads. The generator leads to the switchboards must run as inconspicuously as possible. They are laid in the floor either in tile, loricated, iron, or other approved ducts. A more convenient way, particularly in large-sized plants, is to run the leads in trenches or tunnels, on insulators; and must be so arranged that the cables may be easily inspected; and free from any possible chance of short circuit. The size of the leads is always specified by the manufacturer.

High Voltage Generators. The advantages of high voltage generator plants lie in lower first cost, low operating expenses, simplicity in station wiring and better line regulation. With the employment of high voltage generators, transformers and their attendant troubles are eliminated. A 30,000-volt generator is, of course, more expensive than a 6000-volt or other low voltage generator. However, taking into consideration the step-up transformers necessary with low voltage generators, the cost for high voltage generators is lower; further, with the latter equipment, the power house is smaller and therefore less expensive.

The simplicity in the station wiring is at once evident; there are no low tension bus systems, with switches, transformers and measuring instruments, therefore no special low tension compartments are necessary. However, better and more expensive instrument transformers are required. The operating performance of the station is simplified, there being no step-up transformers to look after when generators are put into service; when generators are to be run in parallel and thrown on the line, all that is necessary is to bring the incoming machines to synchronism and

throw them onto the bus. The absence of transformers relieves the system of surges, attendant when throwing unloaded transformers onto the busses.

That there is sufficient reliability in operating high voltage generators is proven by the number of such generator plants on the continent of Europe; for instance, the 20,000-volt, 3-phase, 15-cycle generator plant at Ponte de Desco, operating the Valtellina Railroad, Italy. Further, a 15,000-volt, 42-cycle, 2-phase generator plant at Jaruga, Dalmatia, which has been in operation since 1903, feeding a six mile aerial transmission system.

Owing to the successful operation of this latter plant, in 1906, another plant (Manojlovac, Dalmatia) was put into operation by the same company for the same purpose. This plant possesses four 6000-HP. Francis turbines, directly connected to 42-cycle, 3-phase generators, making 420 R.P.M. The 30,000 generator-voltage is transmitted over a twenty-one mile aerial line.

SWITCHING ROOMS.

General Arrangement. The switching rooms are located either in the power house itself or in a separate building. The latter is exclusively done in connection with large power plants; in such cases only the controlling apparatus are located in the power plant, while the entire switchgear for the outgoing feeders is in a separate building, some distance away. Examples of this arrangement are that of the Ontario Power Company, and the Canadian-Niagara Power Company. However, in smaller and average sized plants the whole switchgear is embodied in the generating plant, and if transformers are necessary they are located in the same building or in an annex. The majority of hydroelectric power plants are of the latter type.

It is decidedly bad practice to have the whole switchgear located in one single room. It must be separated regarding high and low tension, transformers, etc., either on separate floors or separated by partition walls. An example of this kind of arrangement is given in Fig. 1, representing the relation of the various divisions of the Obermatt, Lucerne, power plant. It is considered one of the best Swiss plants.

It will be observed that the switching apparatus is located on three floors. The two lower are each separated by two longitudinal division walls; the upper is located in the tower-like structure from whence the long distance lines leave the building. The 6000 generator-voltage is stepped up to 27,000 volts through transformers located in an annex, longitudinal to the switching room.

Good examples of American switching room practice are given in Figs. 3 and 4. Studying the cuts of the Shawinigan Falls Power Plant,[1] it will be observed that the 2200 generator-voltage is led to a separate switchboard, controlling the 25,000 and 50,000-volt transmission groups. Beneath the switchboard gallery in the generating room are the oil switches, while the two groups of lightning arresters are

[1] Electric Power from Shawinigan Falls, Canada, by W. C. Johnson, *Cassier's Magazine*, June, 1904.

kept in separate compartments. Another very interesting arrangement of switching rooms is that of the Puyallup River plant of the Puget Sound Power Company, near Tacoma, Washington. Owing to the fact that the plant is located on the

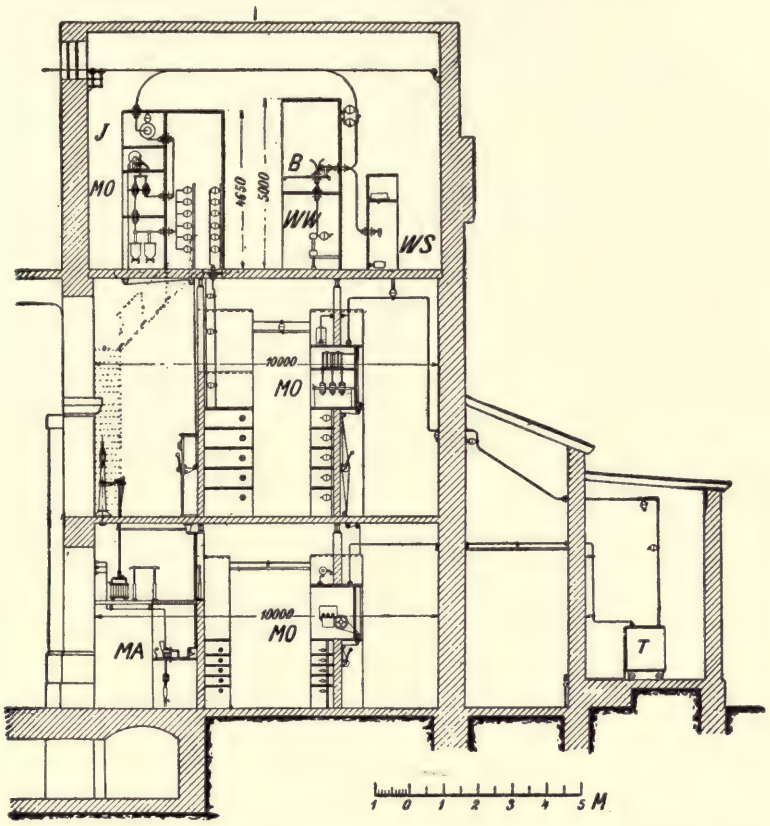


FIG. 1.—Cross Section of Obermatt Transformer and Switch Rooms.

MA = Circuit Breakers.
MO = Overload Switches.
T = Transformers.
J = Induction Coils.
B = Horn Gaps.
WW = Water Rheostats.
WS = Water Flow Grounder's.

hillside, the whole switching gear is located in two adjoining buildings as seen in Fig. 5.[1]

The transformer rooms are at the same level as the generator room, but isolated from the latter by rolling steel doors. On floor No. 2 are the low tension disconnecting switches, the generator and transformer cables going to the sets of disconnecting switches on either side of the middle partition; the disconnecting switches are

[1] *Electrical World and Engineer*, October 8, 1904.

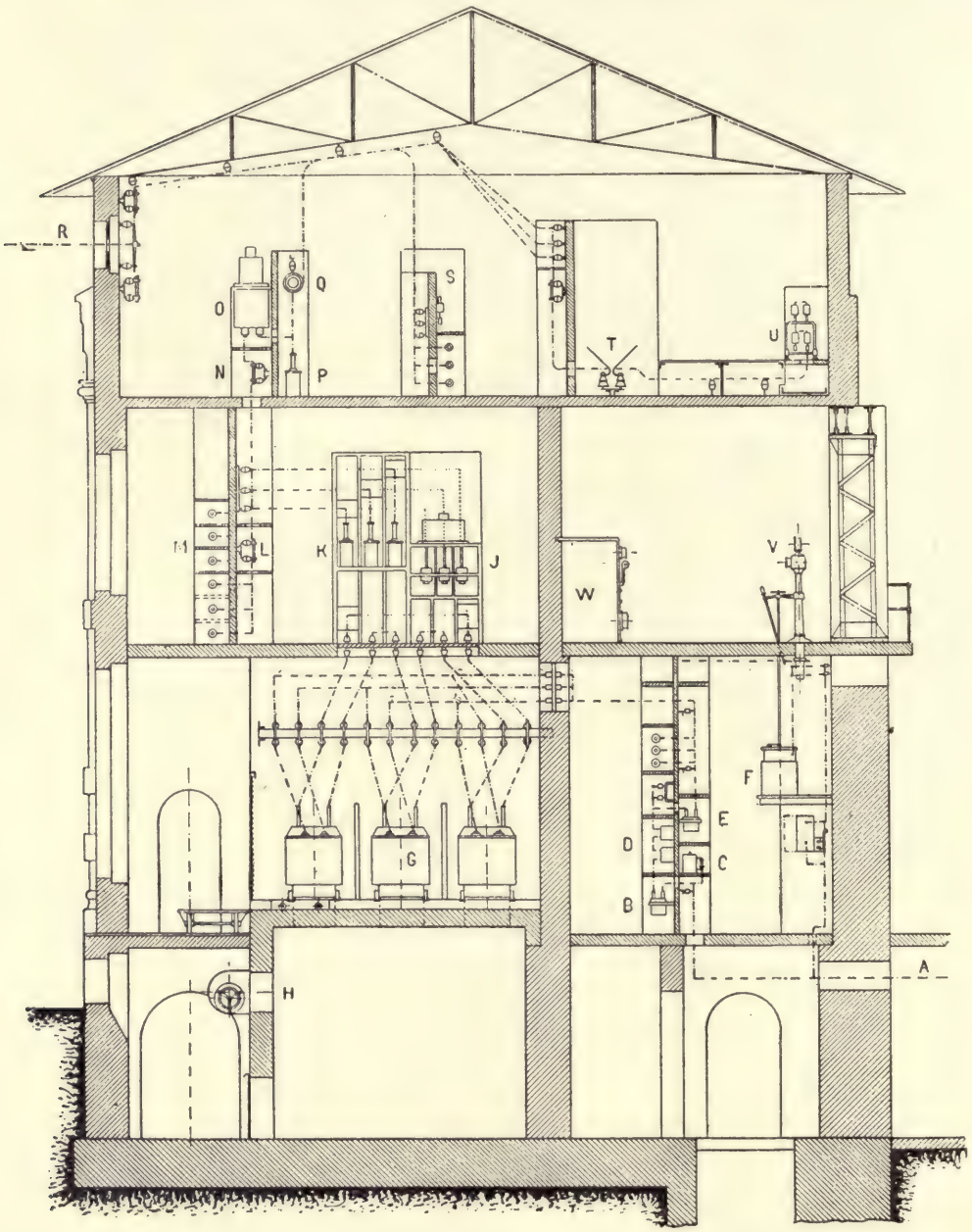


FIG. 2.—Castelnuovo-Valdarno Plant. Cross Section of Switch House.

A-Generator leads; B-Circuit breaker 6000 V.; C-Potential transformer; D-Series transformer; E-Selector switch; F-Generator rheostat; G-Transformers; H-Blowers; J-Circuit breaker, 33,000 V.; K-Series transformer, 33,000 V.; L- and N-Hook switches; M-Busbars, 33,000 V.; O-Circuit breaker, P-Series transformer; Q-Choke coils; R-Outgoing line; S-Ground-detector; T-Horn gaps; U-Water rheostats; V-Instrument column; W-Switchboard.

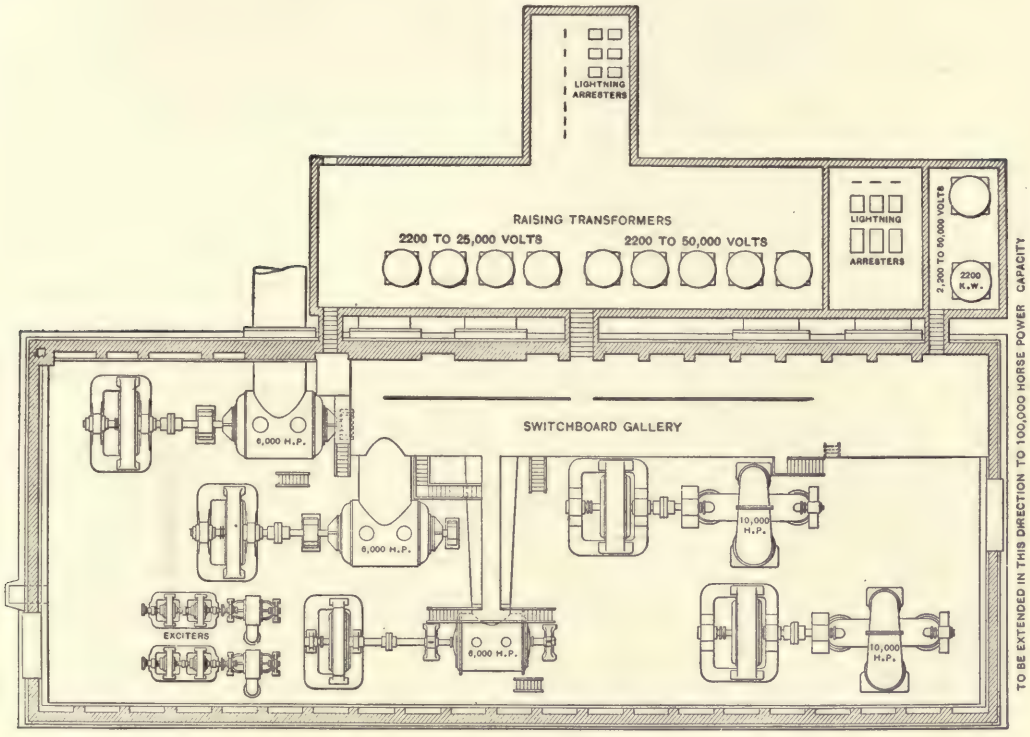


FIG. 3.—Plan of Shawinigan Falls Plant.

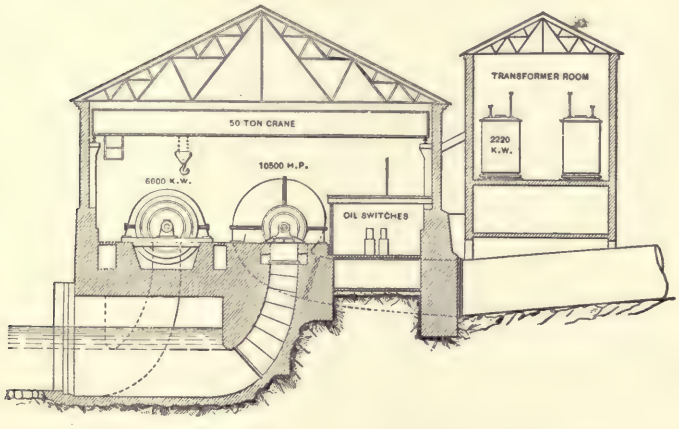


FIG. 4.—Shawinigan Falls Power Plant.

installed between the oil switches and the bus, being on the outer walls and immediately below the bus bar compartments, which are above on floor No. 3. In the center of floor No. 3 are the low tension oil switches, the two oil switches corresponding to a generator or a transformer bank being arranged back to back and facing their corresponding set of bus bars.

The bus bars are of the laminated type, consisting of flat copper bars with expansion joints, and supported on marble slabs set on edge, which in turn rest on concrete slabs, forming barriers between adjacent bus bars. The compartments formed by the concrete slabs are covered by insulating fireproof doors.

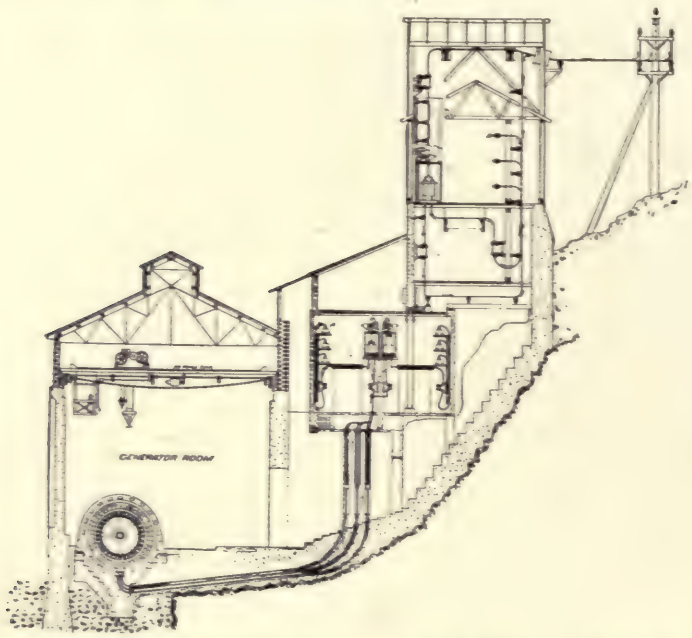


FIG. 5.—Section through Generator Room and Switchhouse, Puget Sound Plant, Puyallup River, Washington.

The oil switches are installed in brick cells with soapstone bottom and top slabs and doors. Each pole of a switch is separated from the others by brick barriers. The same general scheme is used for both the high and low tension disconnecting and oil switches, except that only one set of high tension bus bars is at present installed, provision being made for later installation of the second set. The high tension disconnecting switches and current transformers are on floor No. 5, while the high tension oil switches are on floor No. 6. Above floor No. 6 are the two outgoing high tension line towers, in the north end of which are the high tension lightning arresters, each pole being separated from its adjacent pole by brick barriers extending the full length of the arrester. The lines emerge from the wire tower centrally through an extra heavy 30-inch sewer tile covered by a glass plate.

SWITCHBOARDS.

Object. The object of the switchboard is to collect the generated current for the purpose of controlling, measuring and distribution of same. The structure and apparatus mounted on same should be fireproof, and so arranged that easy access may be had to all parts to facilitate inspection and repair. The arrangement of the apparatus as well as the whole switching gear must be simple and symmetrical



FIG. 1.—50-cycle, A.C. and D.C. Switchboard, Necaxa Power Plant, Mexico.

to prevent as much as possible the making of wrong connections; the number of instruments and protecting devices must be sufficient to secure a flexible and continuous operation. All live parts, especially those of high potential, must be eliminated from the front of the switchboard. When installing a switchboard, provision must be made for further extension.

In laying out a switchboard, either for direct or alternating current, each generator or machine must have its own panel; and the various panels for the same type of machines should be in a separate group; according to American practice, for instance, all alternator panels should be together, so that they can be operated from a central panel when working in synchronism.

European practice is virtually the same as the above; however, in a very recent installation at Brusio, Switzerland, each generator has its own switchboard directly opposite the generator. When the various generators are working in parallel they are controlled from a single instrument column in front of the exciter switchboard

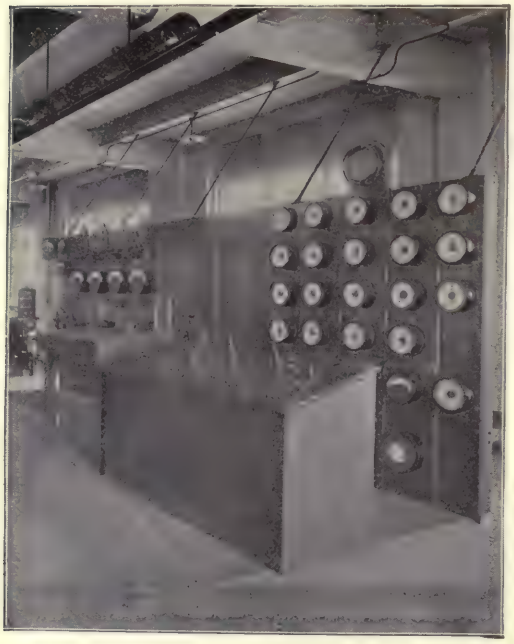


FIG. 2.—Westinghouse Type of Panel and Bench Desk Switchboard.

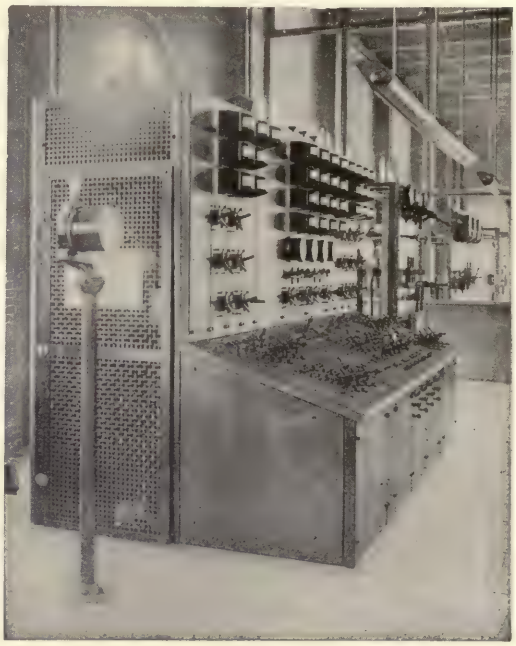


FIG. 3.—General Electric Type of Panel and Bench Desk Switchboard.

in the middle of the generating room. This system was adopted owing to the great number of generators installed. The generator attendants of the various machines look after the switchboards, while the outgoing feeders, of which there are few, are controlled from the above central instrument column.

The leads from generators come to the switchboard from beneath, and the outgoing feeders usually leave from the top. The latter particularly must be well arranged and inconspicuously placed.

Types. Switchboards are either direct or remote controlled. For voltages, both alternating and direct current, the switches under 600 volts are direct control, while above this they are remote control, either by mechanical devices, such as bell cranks, rods, and gears, or electrically by solenoids or motors. There are a few installations

where the remote control system is operated by compressed air, but such a system is not favored in present practice.

The switchboards installed are for direct and alternating current. The direct current board is used principally for controlling excitation and the alternating for controlling the output of the main generators. In isolated plants for small industrial purposes, having no long transmission lines, a common switchboard is usually employed.



FIG. 4.—Generator Instrument Columns, Obermatt Plant, Luzerne, Switzerland. Oerlikon Co.

Panel Type. Under switchboards one finds different types, such as panel, pedestal or column, and desk or benchboard. The panel type usually has mounted on it the entire switchboard equipment. In many instances however, in recent high tension practice, the switchboard has only on the front the meters and other indicating instruments, while the controlling switches are placed on a desk or bench in front of the panel or instrument board. These boards are made up of structural steel or pipe frames faced with white or blue marble or slate slabs. The marble presents a much finer appearance, but it readily shows oil stains and scratches, and if the board is extended at any future time it is difficult to match the panels. Marble

panels are chiefly used in isolated plants, and in central stations in Europe, in which case the panelboard is made very ornate.

In most American central plants and substations slate with dull black or oil finish is used. It has the advantage of having a uniform shade, while scratches and oil spots are readily eradicated, also the instruments stand out in a bolder relief. The back of the switchboard for low tension wiring must be at least from 3 to 4 feet away from the wall and thoroughly braced at the foot and top. The sizes of the

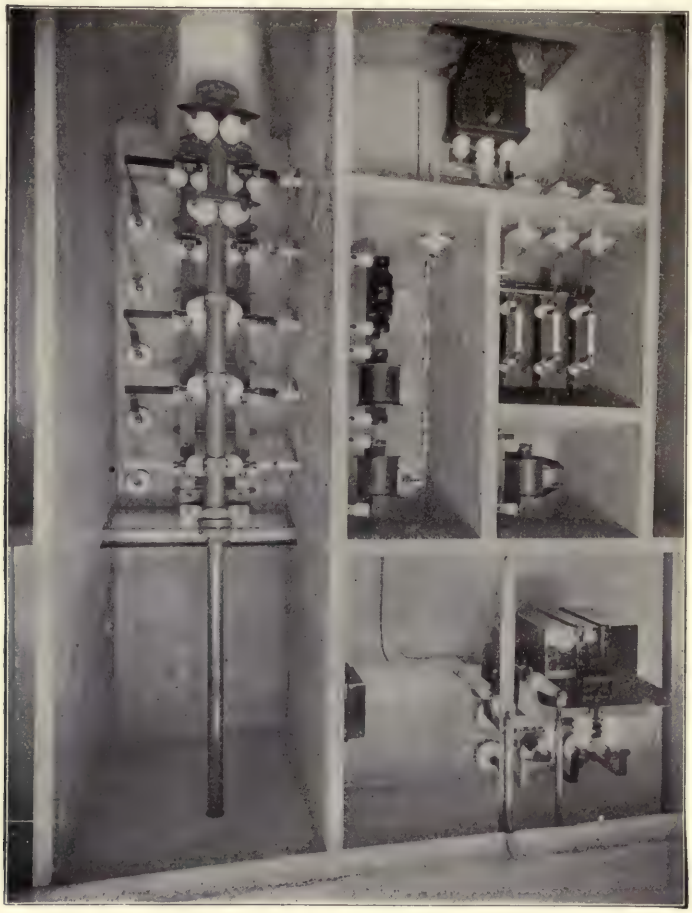


FIG. 5.—Apparatus in back of 2000-K.W., 6000-volt Generator Switchboard Panel, Obermatt Plant, Luzerne, Switzerland.

panels are practically standard. For instance, the General Electric Company's panel consists of two slabs, the lower one 28 inches high and the upper one 62 inches high, the width being 24 inches. The power section of the Westinghouse panel is 25 and the upper 65 inches. The Westinghouse panel is sometimes made up in three sections, the lower being 25, the middle 45, and the top 20 inches, the upper being primarily made for the mounting of a circuit breaker to enable easy removal in case of repair and substitution.

Pedestal or Column Type. For controlling a single generator, a pedestal or column with all the necessary switches, instruments, etc., mounted on same is employed. In most cases, they are arranged in front of the feeder panel board, with the back of the column toward the generating room, so that the operator faces the instruments and generating room. A novel arrangement of pedestal and columns has been adopted by the Ontario Power Company, where they are arranged in a semi-circle, and easily overlooked from the desk of the chief operator.

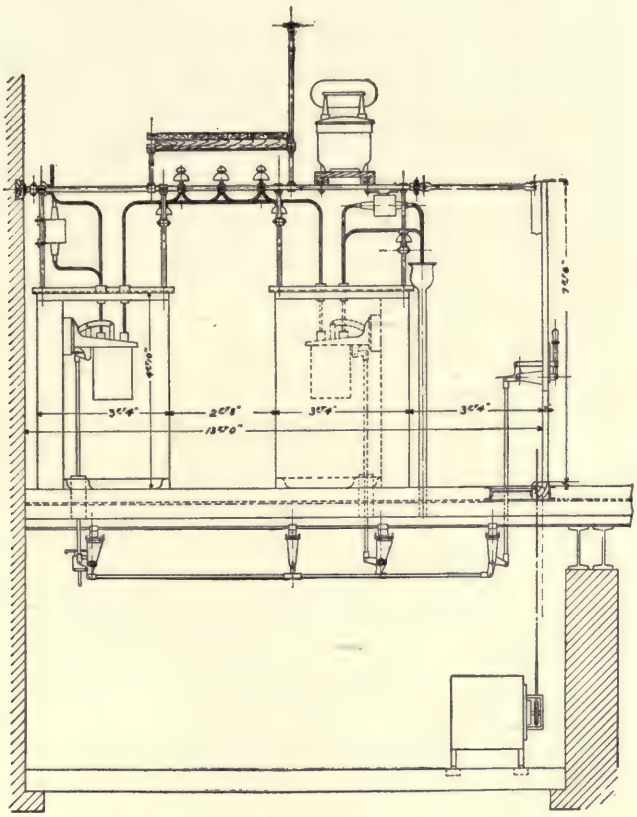


FIG. 6.—Cross Section of Generating Station Switchboard Arrangement, with Oil Switches for Remote Control by means of Switchboard Lever.

Desk or Panel Board. The desk or bench board are chiefly used for controlling the main oil switches, both of the generator and outgoing feeders. They are equipped with pilot switches and lamps, for operating the main circuit breakers, field switches, field rheostats, governor, motors, etc. These benches are usually placed in front of the instrument board, and must be so arranged that the panel of one circuit is directly behind the section of the same circuit on the controlling bench. To further facilitate operation, the panel and control bench are provided with card holders or name plates to classify the groups. In addition, dummy bus bars are mounted on the bench.

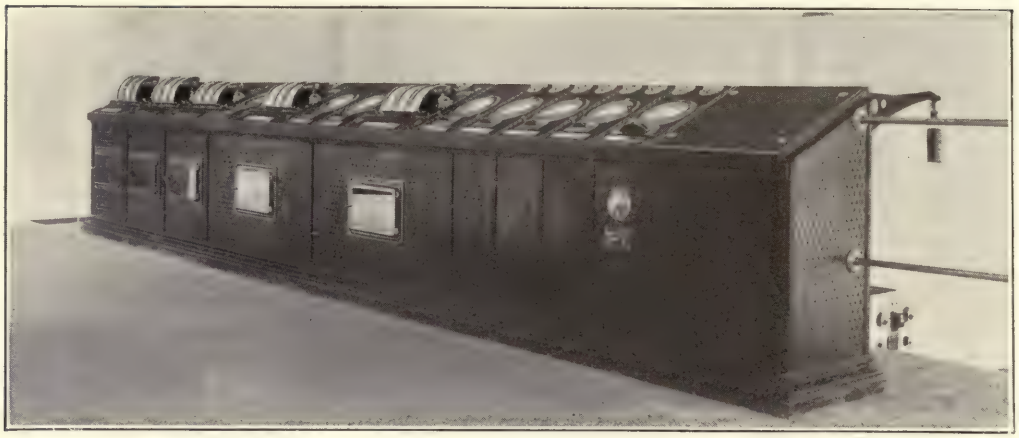


FIG. 7.—Instrument and Controlling Bench Löntsch Hydroelectric Plant, Switzerland, Brown, Boveri & Co.

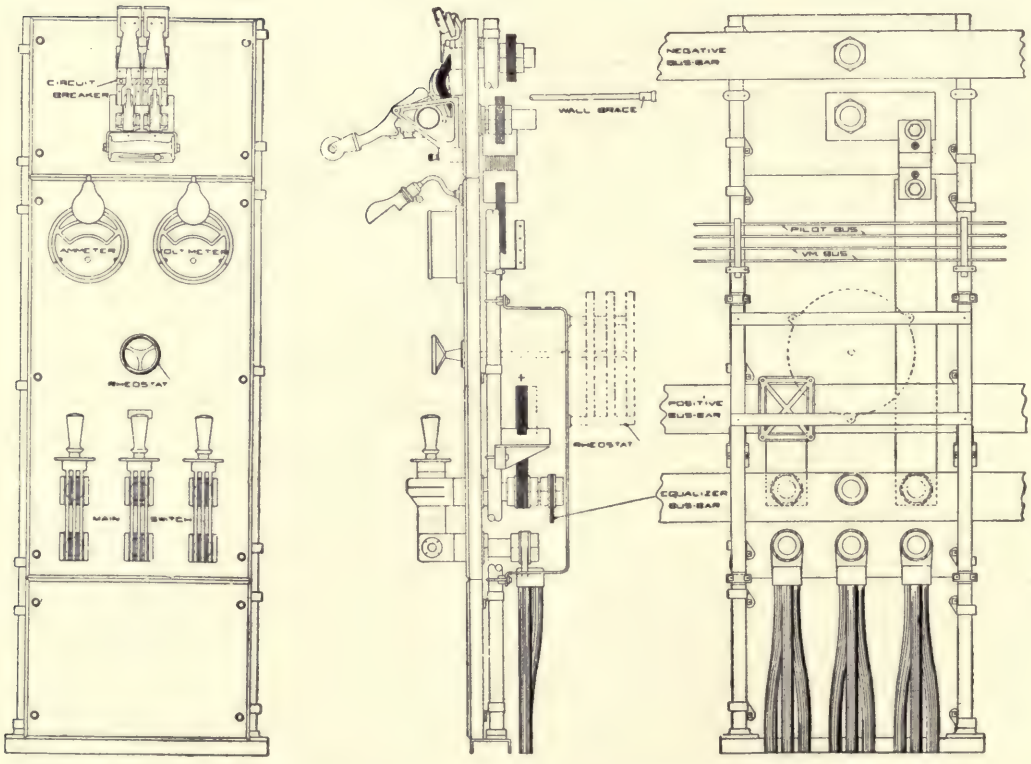


FIG. 8.—Typical Exciter or D.C. Generator Panel Arrangement (Walker Electric Co.).

Where it is desirable that the switchboard operator should command a view of the bench, panel board and the generating room at the same time, the bench and board are placed back to the generating room with the board elevated on posts, with a space of 3 to 4 feet between the top of the bench and the bottom of the panel board. In some of the European plants, the designers entirely dispose of the instrument board by mounting the instruments and the controlling devices on a common bench. It is common practice to place all switchboards, columns and benches for controlling generators and outgoing feeders on galleries or mezzanine floors.

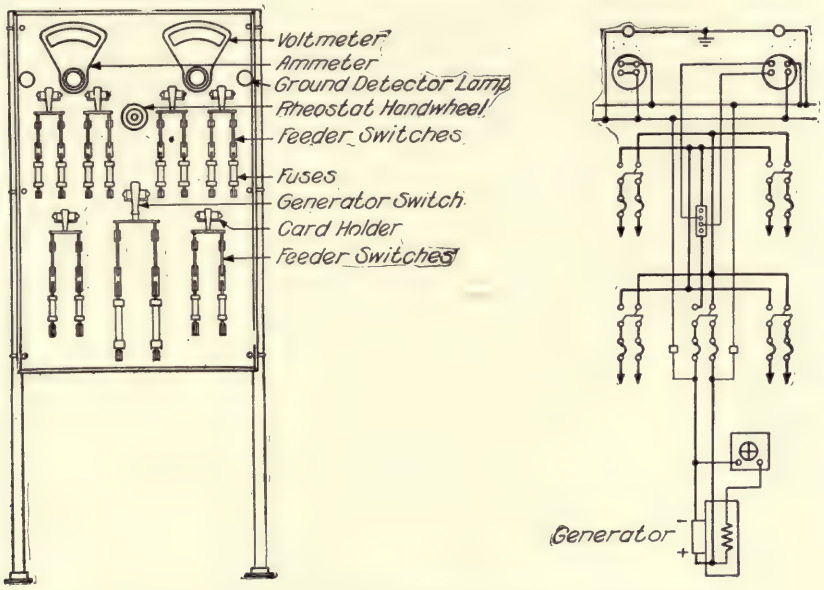


FIG. 9.—Typical D.C. Combination Panel Switchboard.

Direct Current Board. The direct current board is usually made up of one panel for each exciter unit, containing a voltmeter, ammeter, main and field switch, circuit breaker and field rheostat, field discharge resistance, also equilizer switch for parallel operation. In some cases the latter switch is placed on a stand near the machine or mounted on the machine itself. In modern practice this exciter switchboard is placed on the main operating floor near the exciters, although in some cases they are placed on the operating gallery with the rest of the control apparatus. The circuit breakers on exciter panels must be non-automatic, while on D.C. generator panels it is essential that they are automatic. The reason for this is that the exciter current must not be interrupted except when the main unit supplied by it is shut down. For ordinary direct current distribution, the switchboard is divided into two parts, the generator panels and the feeder panels. The above-mentioned instruments are mounted on the generator end, while on the feeder end each feeder panel has an ammeter, integrating wattmeter, circuit breaker and single throw knife switch. In many cases there is a totalizing watt meter connected to the feeder busses. Where the switchboard is provided with two sets of busses, the feeder panels are provided

with double throw knife switches, so as to connect onto either bus. Fig. 8 shows a typical arrangement of a direct current generator panel with only one set of busses and an equilizer bus. Another type of D.C. switchboard equipment is seen in Fig. 9. It will be observed that it contains the necessary instruments for the generator and switches for feeder circuits, as the feeder circuits do not contain any instruments it is a typical switchboard for an isolated plant.

Low Tension A.C. Boards. — In isolated plants supplying light and power for manufacturing, low tension three phase and two phase is usually employed, or some modification, for instance, a 4-wire, 3-phase or a 3-wire 2-phase. The voltage varies from 200 to 600. Fig. 10 shows a typical layout of a low tension, 3-phase

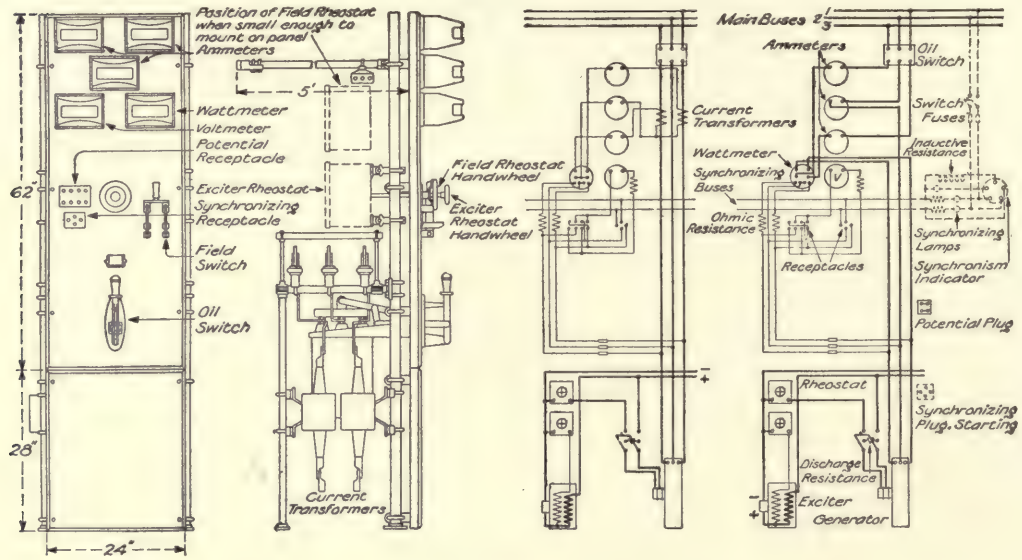


FIG. 10.—480 and 600-volt, 3-phase Generator Power with Three Main Ammeters, General Electric Company.

generator panels as designed by the General Electric Company. These switchboards are equipped with either three or a single ammeter. When three are used, there is one for each phase, while when one is used, it is assumed that the phases are balanced so that one meter is sufficient, being continuously connected to one phase, or by means of a receptacle and plug, connected to any of the three phases. All alternating current boards always have an oil switch for a main switch. Where there is a number of such panels, the synchronizing voltmeter and lamps are placed on a swinging bracket at the end of the board, while each panel is provided only with a synchronizing receptacle. The synchronizing voltmeter is sometimes replaced by a synchroscope or synchronism indicator.

Wagon Panel. A novel feature in switchboard design, in use only a few years on the Continent of Europe, is the Wagon Panel System. Fig. 11 shows a carriage as constructed by the Allgemeine Elektricitats-Gesellschaft, Berlin. It consists of a

A.E.&M.E
UNIV. OF CA

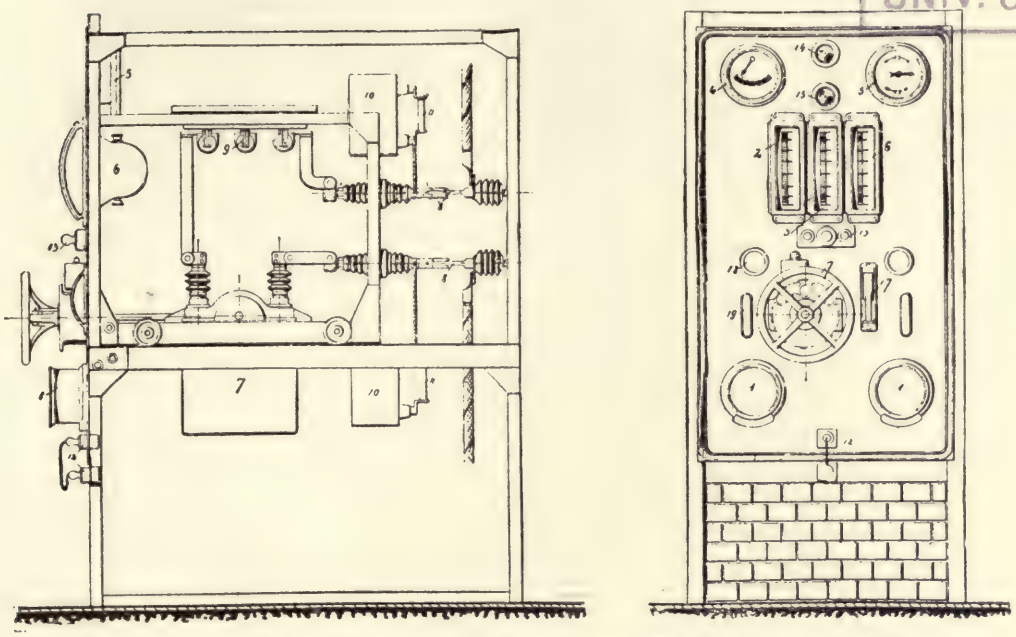


FIG. 11.—Wagon Panel Switchboard of the Allgemeine Elektricitäts-Gesellschaft.

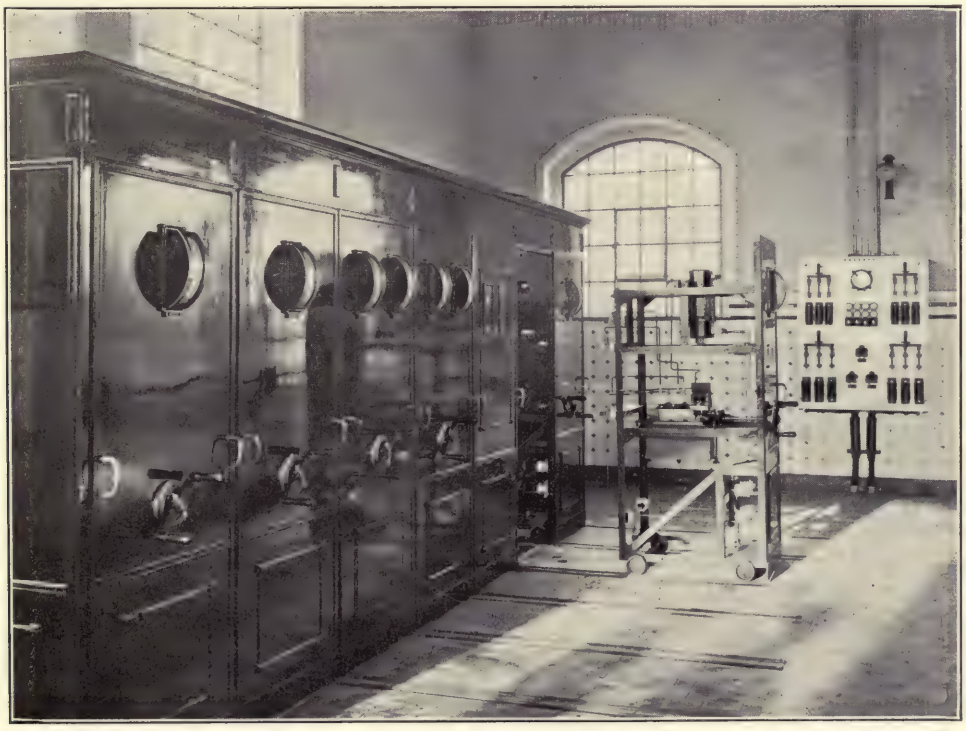


FIG. 12.—Siemens-Schuckert Wagon Panel Switchboard.

carriage running on small wheels upon the structural steel frame of the switchboard and carries the panel with all the instruments. When a panel is to be removed, a portable wagon is backed up to the panel, and the latter is pulled out (each panel is provided with two handles) onto the wagon and removed. It will be observed that the electrical connections do not have to be disturbed as they are similar to a knife

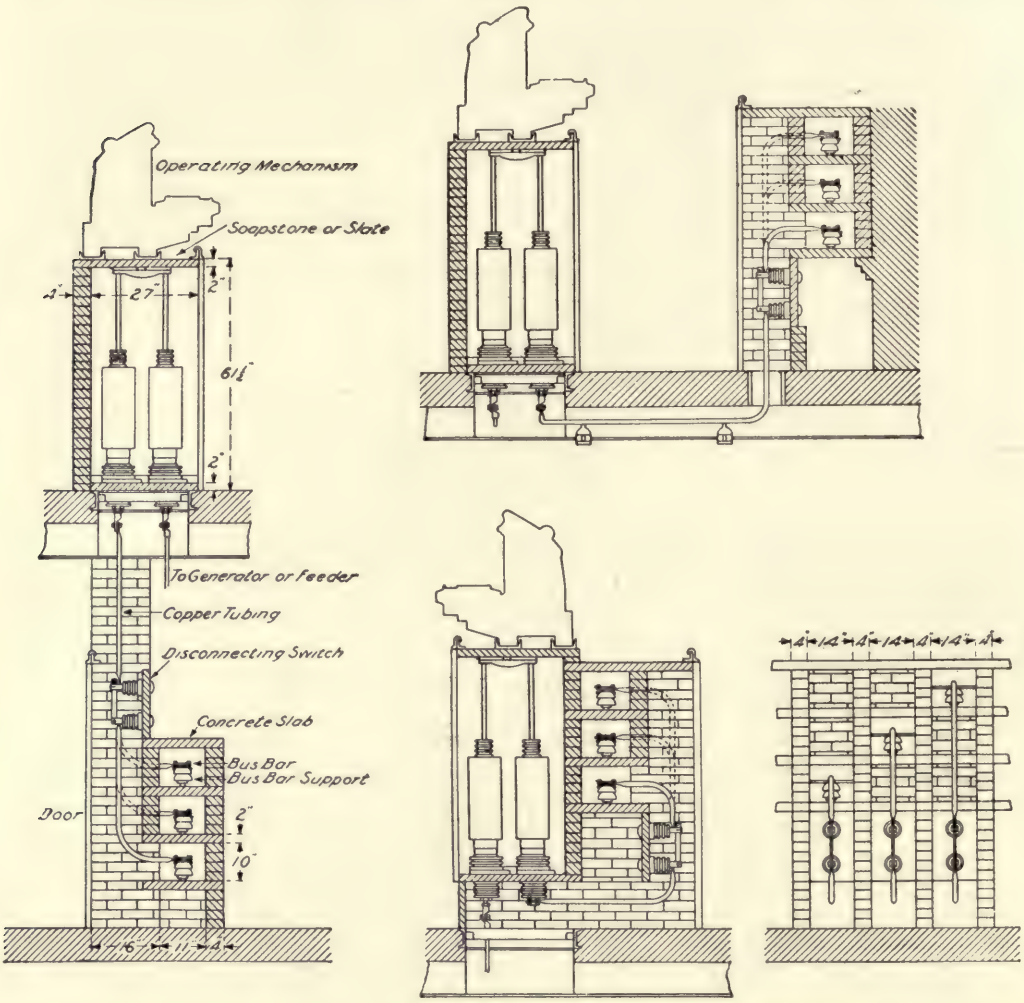


FIG. 13.—Typical Arrangement of 13,200-volt Bus Bars, Electrically Operated Oil Switches, and Disconnecting Switches in a Three-Phase Station, General Electric Company.

blade switch, that is, by means of heavy clips, which make and break the circuit when the carriage is rolled in or out.

In the Siemens-Schuckert System, the entire panel and its equipment is built on a carriage which rolls on tracks in the floor. The electrical connections are made in a way similar to the above. The wagon of each system is so provided with

locking switches, that it cannot be withdrawn while the panel is in operation, which is particularly essential for high tension switchboards.

In the Siemens-Schuckert system the entire panel and its equipment is built on a carriage which rolls on tracks in the floor. The electrical connections are made in a way similar to the above. The wagon of each system is so provided with locking switches that it cannot be withdrawn while the panel is in operation, which is particularly essential for high tension switchboards.

The principal advantage of this " Wagon-panel System " is that a panel can be withdrawn for inspection and repairs and that a reserve panel can eventually replace an old one without disturbing the operation of the remaining units. Thus the danger otherwise encountered in making repairs on the switchboard is eliminated.

High Tension Alternating Current Boards. High tension switches are of the remote control type, that is, the switches are located at a distance from the switchboard, so that the switchboard contains only low tension current apparatus used for operating the high tension switches, thus eliminating the danger of high tension apparatus from the operator. The oil switches are frequently mounted in masonry cells and operated either by motor or solenoid; and as they have no mechanical connections with the switchboard, they may be located at any convenient place. The motors or solenoids for operating the switches are mounted on top of the oil compartments and usually operated by 110 or 220 volt direct current. In some cases the current for operating the switches is taken from the exciter busses, while in others a storage battery is maintained for the purpose.

SWITCHBOARD EQUIPMENT.

Volt and Ammeters. The voltmeters and ammeters are either of the round, sector dial or of the edgewise type. The latter are frequently installed in such a way that they may be readily removed by lifting them out of the swtichboard slab. In some recent European plants the instruments are set so that the faces are flush with the panel. Instruments are always placed on the generator side of the line transformers. Where the voltage is higher than 150, potential transformers are required in connection with the voltmeter. For ammeters greater than 5 amperes series transformers are necessary, and for capacities greater than 800 amperes the series transformers are so arranged, to slip over the bus bar or cable.

Wattmeter. Wattmeters are used to indicate the output of a generator. They are made both indicating and recording. The former gives only the momentary output, while the latter gives a continuous record. With Westinghouse wattmeters, except those for 5 amperes and not over 400 volts, series transformers are required. Where the alternations exceed 3000 and the voltage 200, shunt or potential transformers are required. For the General Electric Company's Thomson Induction Wattmeter a series and potential transformer are necessary only when the amperes exceed 150 and the volts 1150. Fig. 1 shows the wattmeter connections with and without a current transformer.

Synchronizing. To facilitate the synchronizing of generators suitable instruments must be installed. They consist usually of two lamps and a bell, so that when the alternators are out of step this condition is indicated. The lamps are of different colors, green indicating that the machine is running too slow and red that it is too fast. An instrument which indicates this condition more readily, that is, indicating how much the generator is out of step, has been put on the market in recent years under the name of synchroscope and synchronism indicator.

The attendant, when synchronizing a generator, operates a pilot switch controlling the motor on the water wheel governor. Thus when the synchroscope indicates that the incoming machine is too slow, he turns the pilot switch so that the motor will allow the governor to increase the speed of the turbine until synchronism is reached; and the generator is thrown on the bus.

To minimize the time lost in synchronizing, an automatic synchronizer has been placed on the market. When using this instrument the attendant has only to put it in operation and adjust the speed of the incoming generator. At the first instance of synchronism the instrument will automatically throw the machine on the busses.

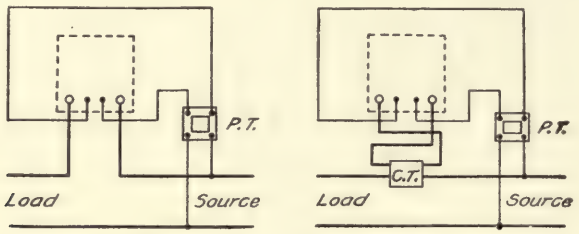


FIG. 1.—Connections of Two Wire Induction Wattmeters.

Power Factor Meter. In most alternating installations the power factor meter is of great value. It is built for single and polyphase circuits and for 3000 and 7200 alternations and in standard sizes up to 2000 volts and 2000 amperes. It indicates directly and accurately results which otherwise can only be reached by computation from readings which if not taken simultaneously may lead to error.

The dial of the power factor meter is divided into four quadrants, each being marked from 0 to 100. These figures represent percentages which would be obtained by dividing the " true watts " in the circuit (as indicated by a wattmeter) by the " apparent watts " (the product of volts and amperes). The angular position of the pointer at any moment also indicates the angular difference in phase between current and voltage. The upper half of the dial indicates the power factor for lagging or leading currents when power is being delivered in one direction, and the lower half gives similar indications for power delivered in the opposite direction. In this way the power factor meter may serve to show a reversal of the direction of power on the line.

In the operation of rotary converters this instrument finds important uses; it simplifies the adjustment of field strength, either for minimum armature current or

to produce some desired effect on the system as a whole. The poor power factors resulting from heavy inductive loads may often be much improved or entirely neutralized by proper field adjustment of rotary converters and other synchronous apparatus. With generators running in parallel the proper distribution of the load can be checked, and in many cases the number of ammeters required may be considerably reduced by the use of the power factor meter.

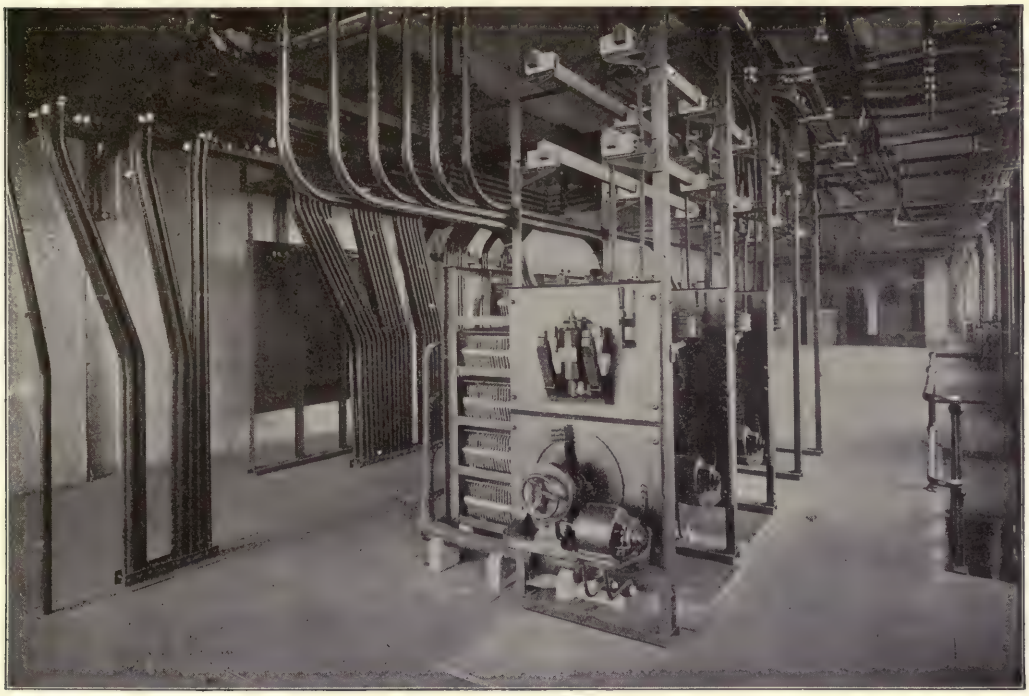


FIG. 2.—Motor Control Rheostat for Field Excitation of Main Generator, Westinghouse Electric Manufacturing Company.

Frequency Meter. To eliminate calculations necessary to ascertain the frequency of a generator, and incidentally the revolutions, a frequency meter may be employed. It may be mounted on the switchboard and occupy the same space as any other indicating instrument. It is built for any frequency with a + or − variation of 25 per cent of the normal. When used on circuits exceeding 100 volts a shunt transformer is required.

Rheostats. Rheostats in generating stations are used for controlling the excitation of generator fields. The rheostats for the exciters, being small, are mounted on the back of the exciter switchboard and in most cases are hand controlled, while those for the main generators are of large size, and have to be placed in compartments which must be well ventilated. These large rheostats are always remote controlled, either by shaft and gearing, much used in Europe, or by motors, common American practice. The pilot switches for controlling same are mounted on the control bench.

Illumination. The switchboard proper must be suitably illuminated so that the condition of switches can at all times be readily seen, also, illuminate the faces of the different meters. Some of the meters have opal glass scales and are illuminated from the rear, making it possible to read the indication from a distance or in otherwise insufficient light. The lamps are inclosed in a compartment separate

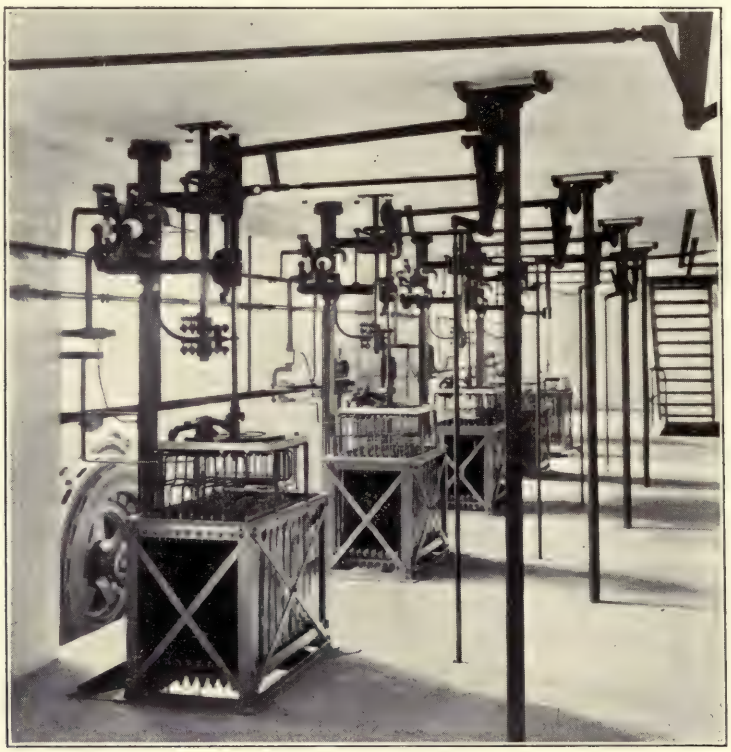


FIG. 3.—Remote Control Hand Operated Rheostats for Field Excitation of the Main Generator, Oerlikon Company.

from the working part of the meter. Where meters with illuminated dials are not installed, a system of incandescent lamps is mounted on the switchboard proper or suspended in front of same, and for either alternating or direct current, but preferably of both to meet emergency.

WIRING DIAGRAM.

Systems. All power plants, whether small or large, depending on continuous operation, must have a double set of bus bars, or the equivalent. The leads from the generators to the bus bars must be so provided with switches that current can be thrown on to either of the systems. For small plants, where there is a light and power load, one bus may be kept separately for light and the other for power. To increase the flexibility of the system, the feeders to and from the bus bars must be

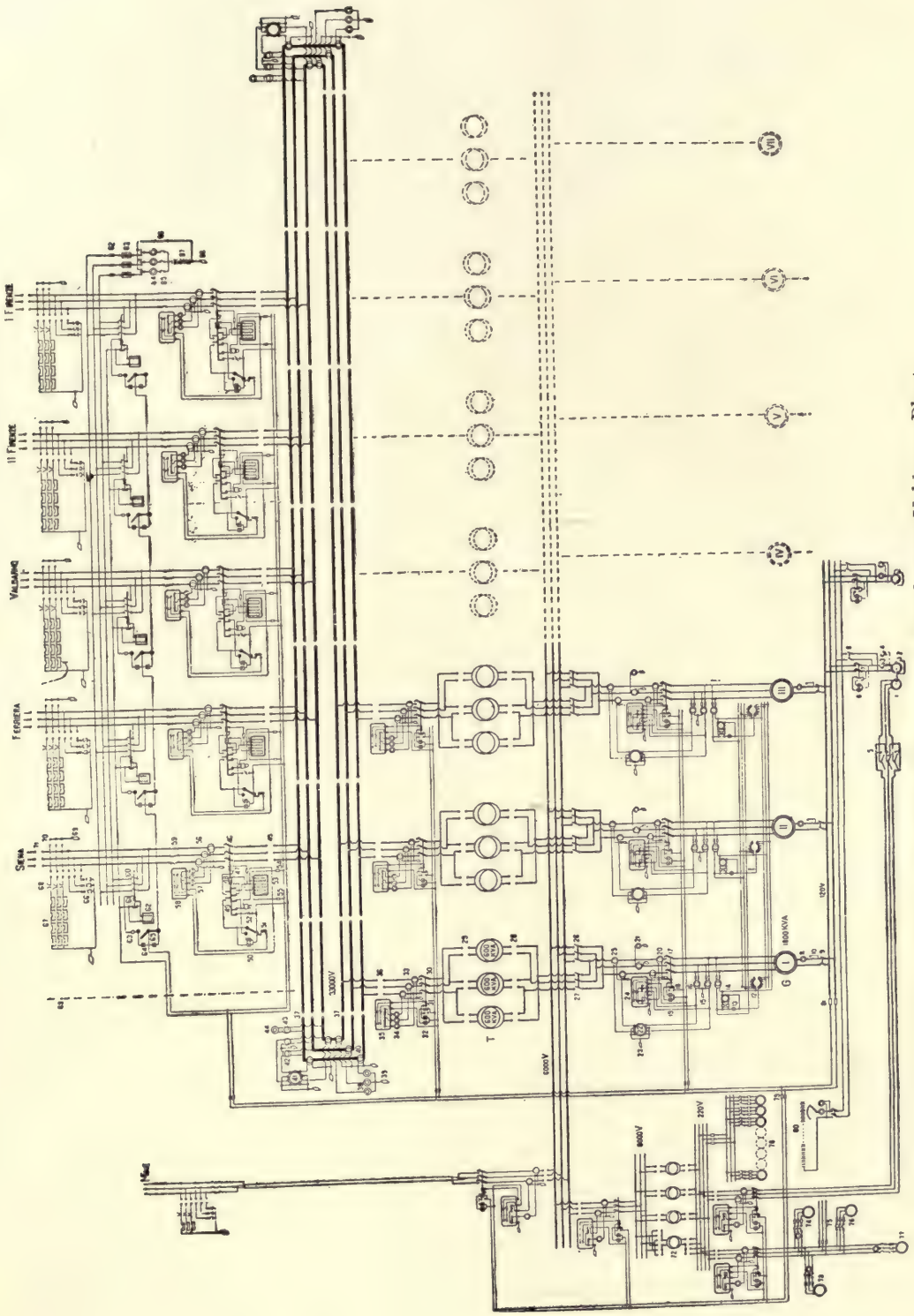


FIG. 1. — Wiring Diagram of Castelnuovo-Valdarno Plant.

such that either or both light and power can be drawn from either of the busses. The leads between generator and bus bars must be provided with a main switch, so that each individual unit may be cut out without affecting the operation of the remainder of the plant. An additional safeguard for continuous operation is to place sectionalizing switches in the bus bars.

In high tension plants where oil switches are used, section or hook switches must be placed on either side of same, so that they may be isolated for inspection and

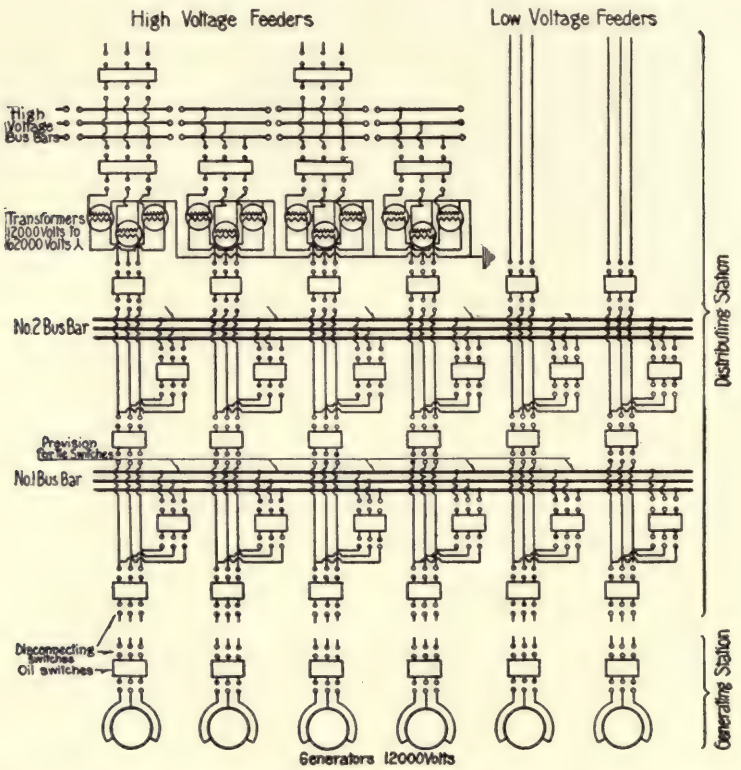


FIG. 1.—Wiring Diagram of Power Circuits, Ontario Power Company.

repair. Where transformers are installed either for stepping up or stepping down, particularly where there are a number, it is advisable to have a bus on the outgoing feeder side. In American practice the double bus bar system for outgoing feeders is seldom used, but will be found to a great extent in Swiss practice, in the form of a ring system.

Fig. 1 shows the general arrangement of the wiring diagram of the Ontario Power Company's plant.[1] It will be observed that the wiring system is simple, yet as flexible as possible.

[1] The Electrical Plant of the Ontario Power Company, by V. G. Converse. Canadian Electrical Association, Niagara Falls, June, 1906.

The generators can be thrown on either of the two low tension (12,000 volt) busses, and the transformers can draw from either of same. It will also be noticed that both high (62,000 volt) and low tension busses are well provided with section switches. The local distribution (12,000 volts) may draw current from either of the two low tension busses.

A somewhat more simplified wiring system is that of the Necaxa power plant, Mexico (Fig. 2). There is only a single low tension (4000 volt) bus bar system.

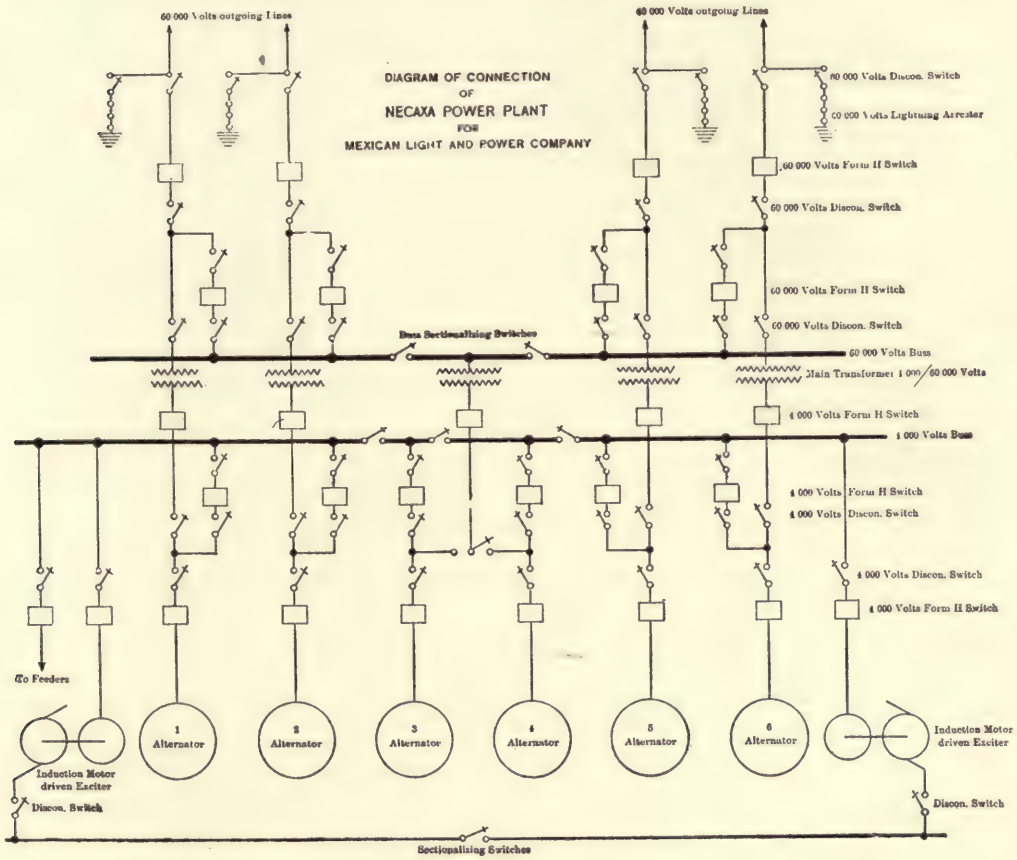


FIG. 2.—Wiring Diagram of the Necaxa Power Plant, Mexico.

The current from the generators may be thrown upon same or directly on the transformers. This would mean that the transformers can draw from the bus bars irrespective of the operation of their own generator. There is but one high tension (60,000 volt) bus bar system.

A wiring diagram in which the generator or low tension bus has been eliminated, although the plant is of large capacity, is that of the Urfttalsperre, Germany. Each 5000-volt generator feeds through a fuse directly to its transformer. The reason for this arrangement is that if a transformer is out of commission the particular

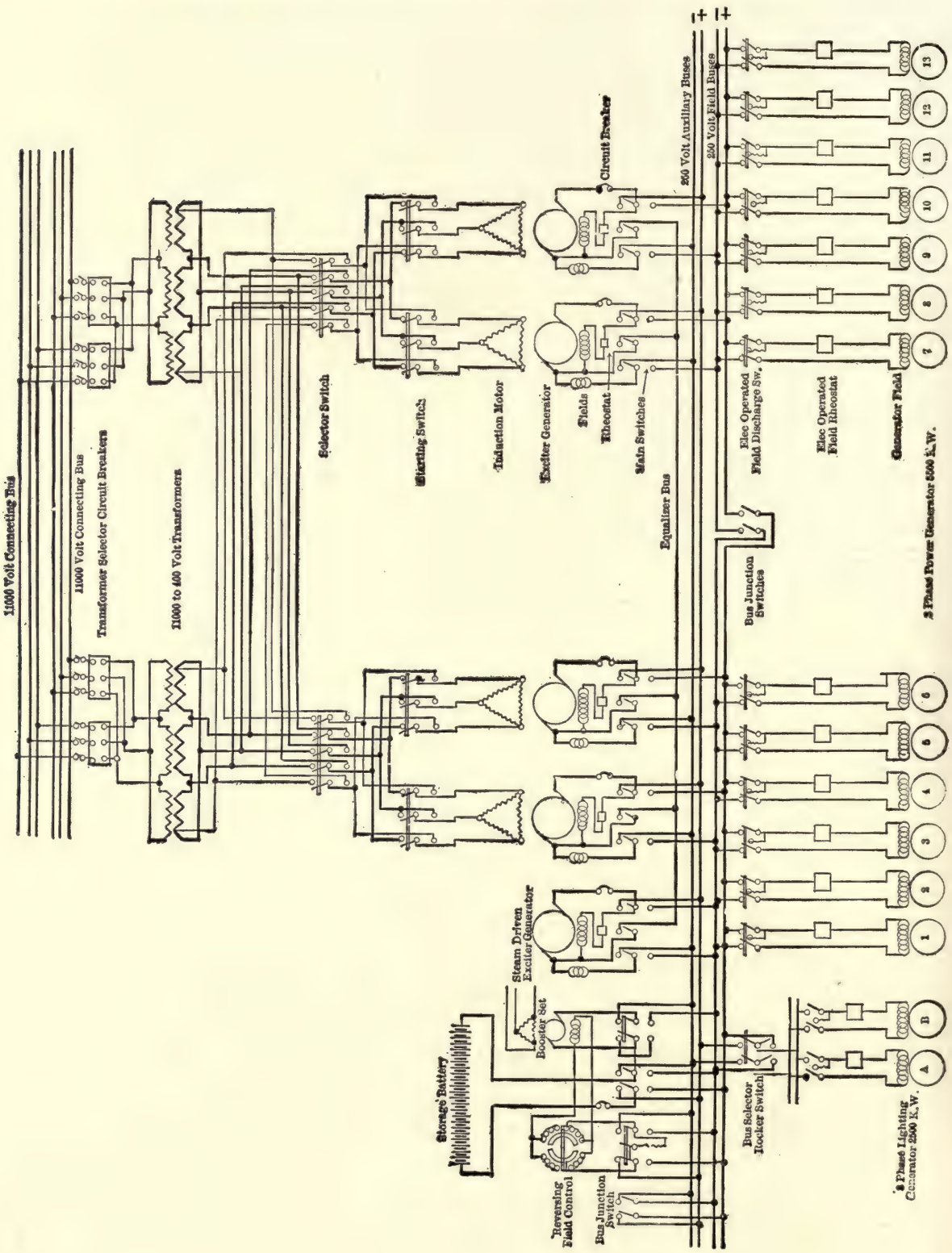


FIG. 3.—Wiring Diagram for Exciters.

generator is shut down and vice versa. The high tension side is tied together with a ring bus bar system, the ends of which are connected through choke coils (see Fig. 4). Between the transformer and bus bar are automatic oil switches. Each outgoing feeder is provided with an automatic oil switch, choke coil, and three-pole tie switch. The outgoing feeders are doubly interconnected with tie switches, so that in fact two ring systems are secured on the high tension side. The whole is amply protected by lightning arresters.

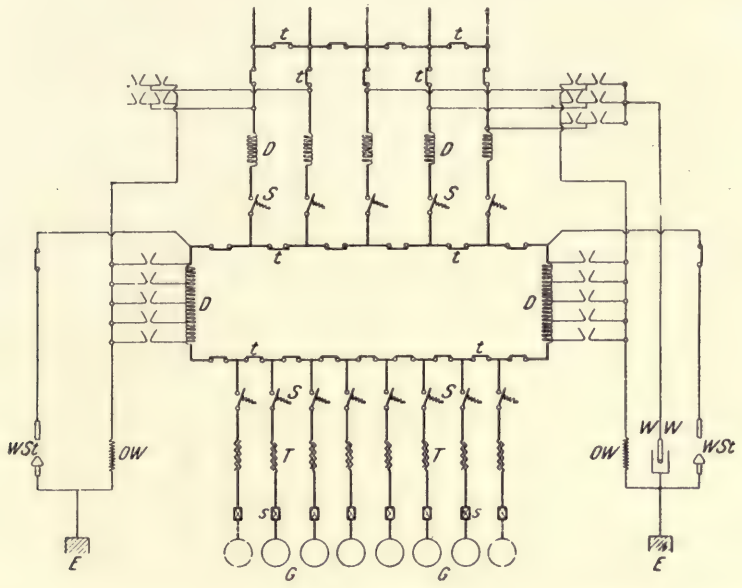


FIG. 4.—Wiring Diagram of the Urfttalsperre Plant, Heimbach, Germany.

G = Generators.	OW = Oil Rheostats.
T = Transformers.	E = Earth.
t = Section Switches.	S = Circuit Breaker.
WSt = Waterflow Grounders.	s = Fuses.
WW = Water Rheostats.	D = Choke Coils.

Considering the protection and particularly the flexibility of the high tension side, it seems strange that the low tension side should be so rigidly connected. It will be readily seen that this plant can be seriously handicapped when a transformer, a generator, and a turbine of different groups are out of commission.

Swiss power plants employ either the double bus bar or ring system. Either one in itself is very intricate. A good example of this kind is given in Fig. 5, and is that of the Obermatt plant, Lucerne. It supplies light and power for various purposes, for which four 2000-HP. generators serve; a fifth generator used exclusively for street railway purposes (located in the left hand of the wiring diagram) is independent of the rest of the plant. As these four generators supply three phase for power or single phase for lighting a certain section, there are two ring bus bar

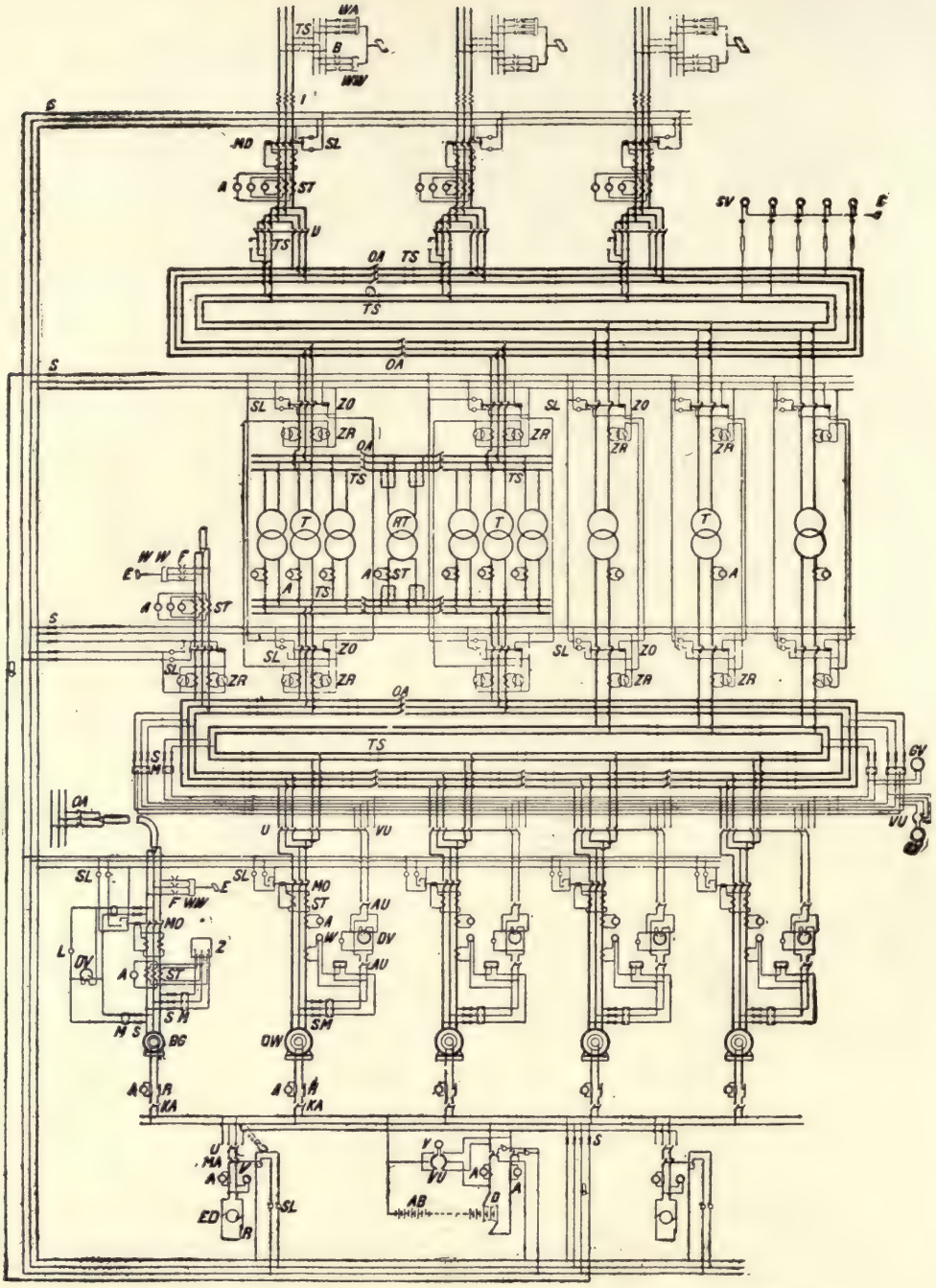


FIG. 5.—Wiring Diagram of the Obermatt Plant, Switzerland.

ED = Exciter.	*MO* = Overload Oil Switch.	*W* = Wattmeter.
GB = Railway Generator	*U* = Double-Throw Switch.	*L* = Phase Lamp.
DW = Three-phase Alternators.	*VU* = Voltmeter Switch.	*SL* = Signal Lamp.
T = Transformers.	*D* = Double-cell Switch.	*WW* = Water Rheostats.
RT = Reserve Transformers.	*TS* = Disconnecting Switch.	*B* = Lightning Arrester.
M = Measuring Transformers.	*S* = Fuse.	*F* = Lightning Arrester.
AB = Storage Battery.	*A* = Ammeter.	*I* = Choke Coils
R = Regulator.	*ST* = Series Transformer.	*WA* = Water Flow Grounders.
AU = Cut out Switch.	*V* = Voltmeter.	*E* = Earth Plate
KA = Carbon Cut-out Switch.	*DV* = Double Voltmeter.	*Z* = Three-phase Ammeter
MA = Overload Switch.	*SV* = Static Voltmeter.	*ZO* = Overload Oil Circuit Breaker.
OA = Sectionalizing Switch.	*GV* = Bus Bar Voltmeter.	*ZR* = Time Relays

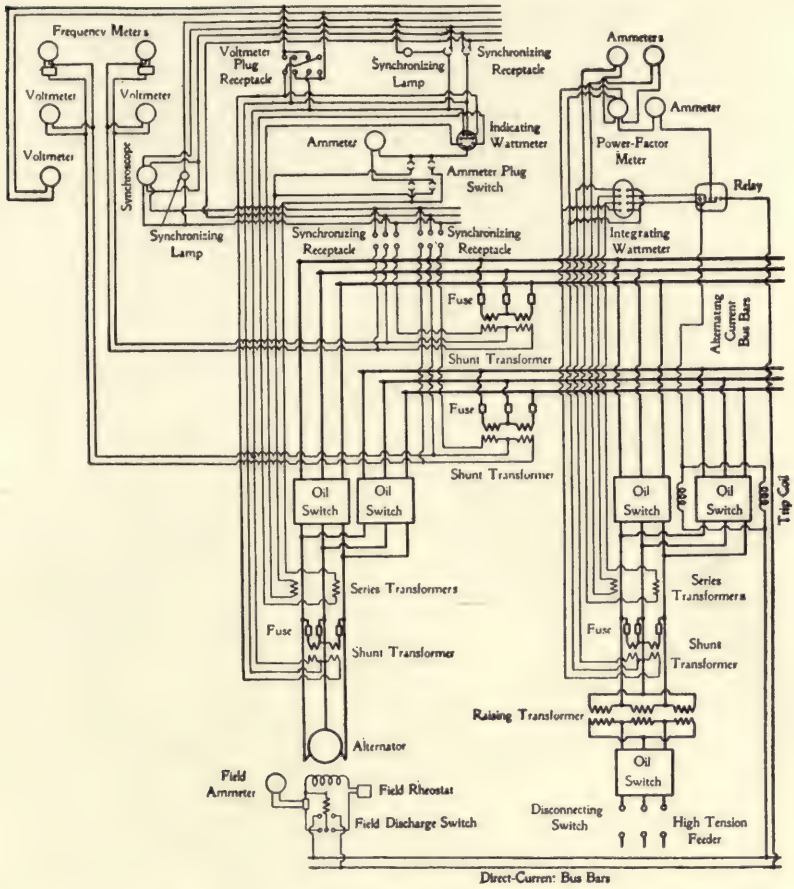


FIG. 6.—Complete Wiring Diagram of a Single Generator and Step-up Transformer.

systems on the low (6000 volt) tension as well as the high (27,000 volt) tension side. The two bus bar systems on either side consist of a single phase and three phase group.

BUS BARS.

Bus bars are made up of cables or flat bars of copper or aluminum. Flat bars, for mechanical reasons, are preferable to round ones, as connections are readily made. Where the bus bars are of short length they may be made of uniform section throughout. However, where the bus bars extend over the entire length of the generating room, as is frequently the case for sake of economy, the bus bars are flat, each of across section area necessary for one generator; thus where a generator lead joins it an additional bus bar section is added.

Size of Bus Bars. The size of the bus bar is determined by the number of amperes it has to carry. From 700 to 800 amperes per square inch of copper is usually chosen as a safe value. For electrical reasons flat bars are better than round ones,

because they present a greater radiating surface thus keeping the resistance from increasing due to heating. This is also a reason in favor of open bus bar compartments.

If aluminum is used in place of copper, the bus bars must have a cross sectional area of 1.66 times that of copper, for equivalent electrical conductivity.

Closed Compartments. Similar to the arrangement for high tension oil switches, the bus bars and disconnecting switches are also placed in masonry compartments. The compartments are made either of brick or concrete, and are entirely closed

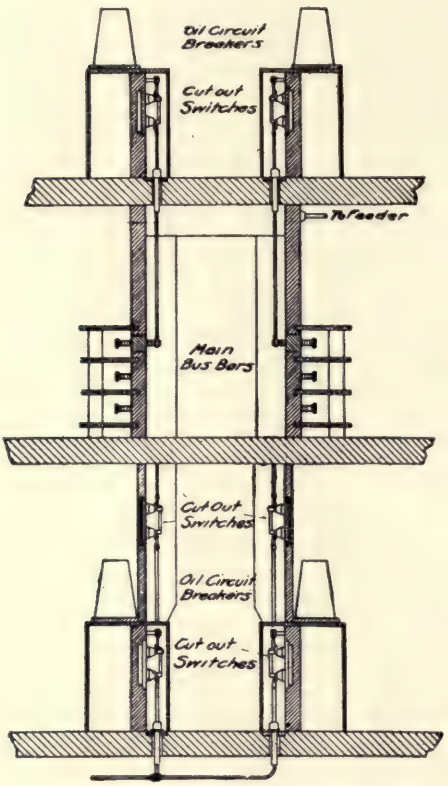


FIG. 1.—Three-Deck Oil Circuit Breaker and Bus Bar Structure. Two Sets of Bus Bars.

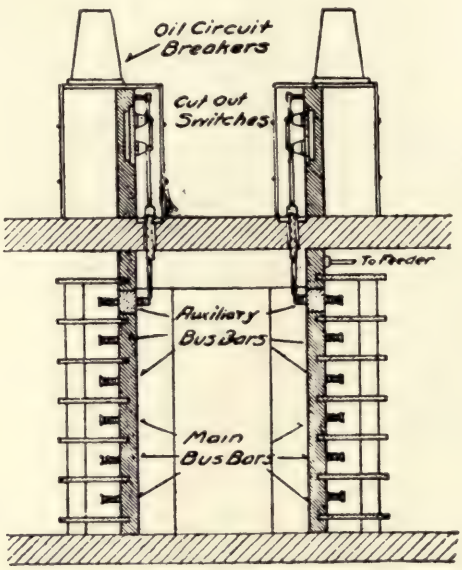


FIG. 2.—Typical American Arrangement of Oil Circuit Breakers and Bus Bars for 15,000 volts or less.

(having access through openings) or else open altogether. With high tension busses, where space is limited, the former arrangement is preferable. The openings to the compartments are about 15 inches square and are staggered. As a means of protection for inspectors and repair men they are best closed with a sheet steel door.

Open Compartments. Where space is plenty, which is usually the case with hydraulic plants, the entire front of the bus bar compartment may be left open. The insulators for carrying the busses are mounted either on the back wall or shelves.



FIG. 3.—6000-volt Bus Bar Room, Obermatt Plant, Luzerne, Switzerland.



FIG. 4.—8000-volt Oppen Bus Bar Chamber, Löntsch Plant, Switzerland.

In order to eliminate posts or partitions for carrying the shelves, the latter are best made of reinforced concrete, giving an unobstructed view of the busses and also facilitating construction, inspection, and repair. Fig. 4 gives an illustration of open bus bar construction at the Löntsch plant, Switzerland. The busses carry 80,000 volts. Another view of Swiss practice is seen in Fig. 3 where no shelves between individual phases are used. There is only one shelf which separates the single phase from the three phase busses (6000 volts.)

OIL SWITCHES.

General Remarks. In modern switchboard engineering one will find the most contradictory practice. Oil switches for 600 volts are designed and installed on the back of the switchboard, operated by a single lever, while on the other hand they are remote controlled. Again, switches for 10,000 volts are mounted directly on the back of the switchboard. Also, with 6000-volt switches, the oil chambers for the individual phases are placed in large and very expensive masonry cells, the access to which is well protected by specially designed fireproof doors; while on the other hand, with 50,000-volt oil switches, all phases are placed in a single sheet metal tank, unprotected and exposed to view. In addition to this, the former is operated by motor or solenoid, the latter by lever and rods. The difference between America and Europe in this practice is clearly indicated in accompanying illustrations.

To go still further in citing the difference existing in American practice, there are 60,000 and 80,000 volt oil switches in operation which have the phases in separate sheet steel tanks exposed to view, being entirely unprotected by masonry construction, as is done in the 6000-volt switches. Even 120,000-volt oil switches of the former type are advocated.

From the foregoing contradictory practice it will be observed that arguments about the danger to the operating force from exposed high tension apparatus are without reason, particularly if one bears in mind that practice has proven that 220 volts may kill as readily as 30,000 volts and higher. It is evident from the above that much could be saved on first cost, maintenance, and floor space in the design of modern oil switches.

Types. Oil switches up to 5000 volts are, according to American practice, of the self contained oil type; they are made up of a sheet steel tank with partitions to separate the phases, and lined with insulating material. The lining and partitions are frequently made of wood. The contacts of the switch are in oil, so that the make and break are made submerged. The phases are usually equipped with multiple break contacts, thus securing a great current breaking capacity.

The practice regarding the operation of high voltage switches varies greatly. In some cases 2300-volt switches are operated by remote control levers, rods, and bell cranks, or by motors or solenoids. In Swiss practice, 10,000-volt switches, in some instances, are mounted on the back of the switchboard and operated by hand levers as seen in Fig. 1. Frequently in American practice switches larger than 5000 kilowatts capacity, the phases are submerged in individual oil tanks and have multiple break

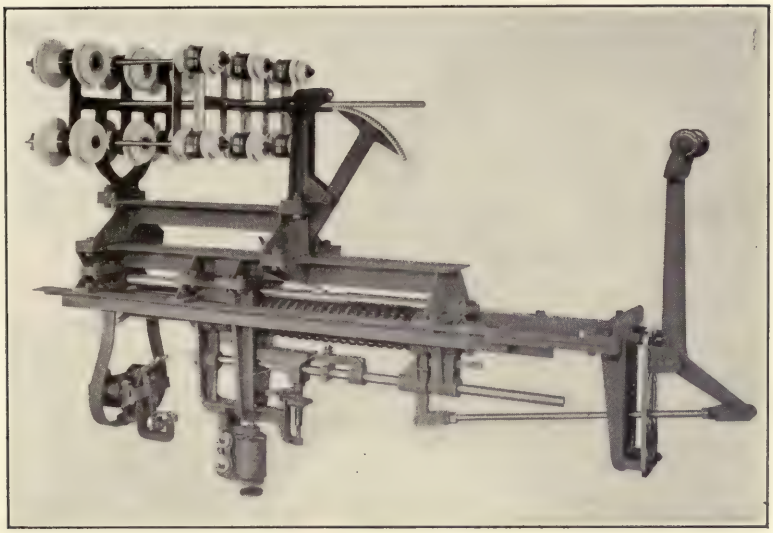


FIG. 1.—Oerlikon 10,000-volt Air Break Switch.

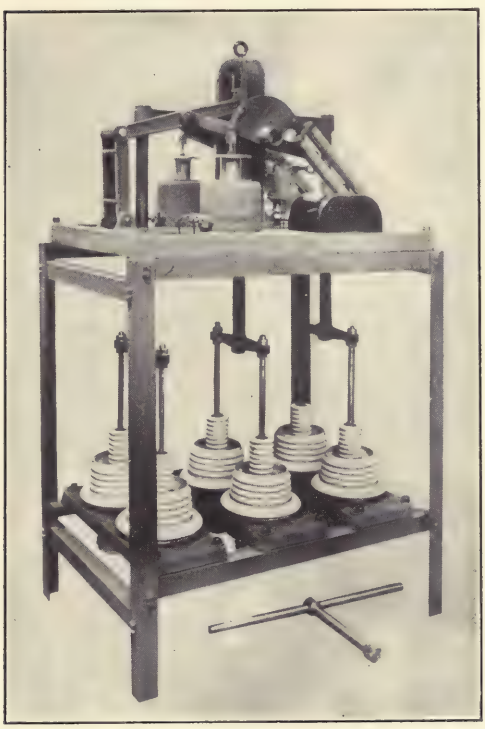


FIG. 2.—Oerlikon 30,000-volt, 300-ampere, Solenoid Controlled Circuit Breaker.

contacts. Each pole of these oil switches is inclosed in a separate fireproof structure made of brick or concrete.

The use of soapstone is not essential and it must be borne in mind that it readily absorbs oil. The doors to the tank compartments are either asbestos fiber, slate slabs, or wire glass, and are held in place by clamps, or hung from the top of the compartment. It is common practice on the continent of Europe to have the poles of all phases for any voltage in one sheet metal tank. In some cases, however, phases are placed in small separate oil tanks and not separated by partition walls. The

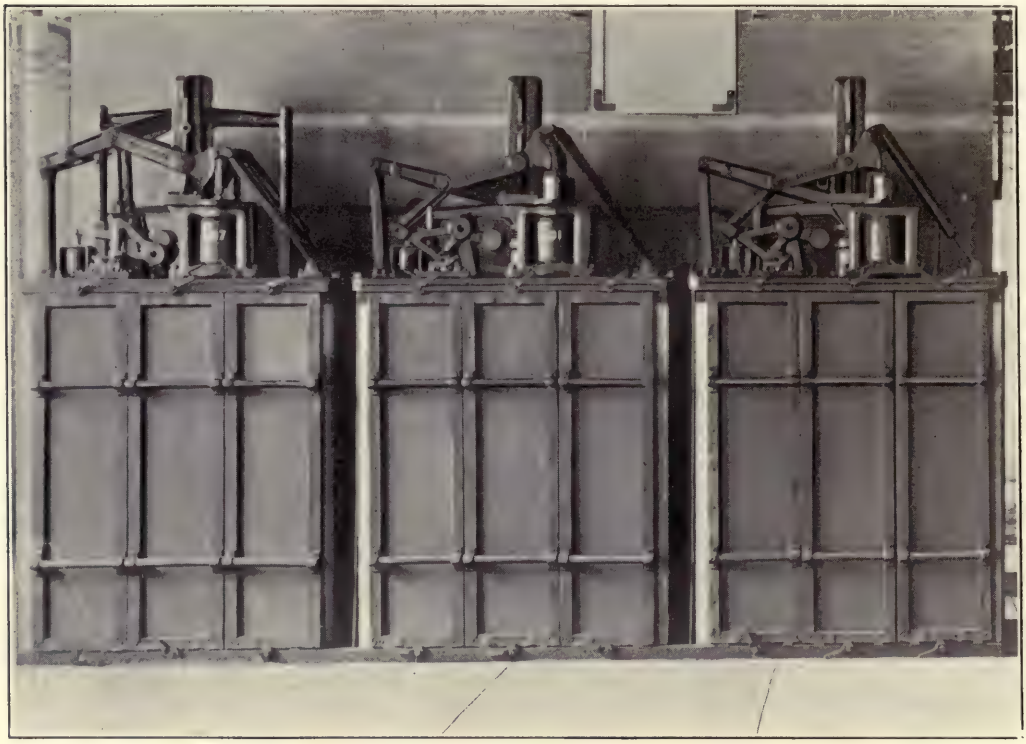


FIG. 3. — Westinghouse 11,000-volt, 600-ampere, Remote Solenoid Controlled, 3-pole Oil Switch.

oil tanks are grouped and mounted on iron frames in compartments of reinforced concrete and always exposed to view. Switches or circuit breakers of this construction have been installed up to 50,000 volts normal capacity (see Fig. 2).

American switches for 60,000, 80,000, 100,000 volts, and even higher are designed on the same principle as those for 30,000 volts. They are either top or bottom connected. The bottom connected switch is arranged with two pots forming one pole of the switch mounted on a common horizontal platform, and is usually operated by a motor. This type of switch requires a comparatively small amount of oil, and has a further advantage, that the circuit is opened in two independent receptacles

A.E.&M.

per phase. According to Hayes,[1] the exposed metal parts of this switch, above the tank and bare terminals below, necessitate the inclosing of the switch in a masonry structure for the protection of the attendant. Doors are provided for each compartment of the structure, to permit the ready inspection of the tanks, etc., but the removal or breaking of a door leaves these live metal parts a source of danger. Such switches

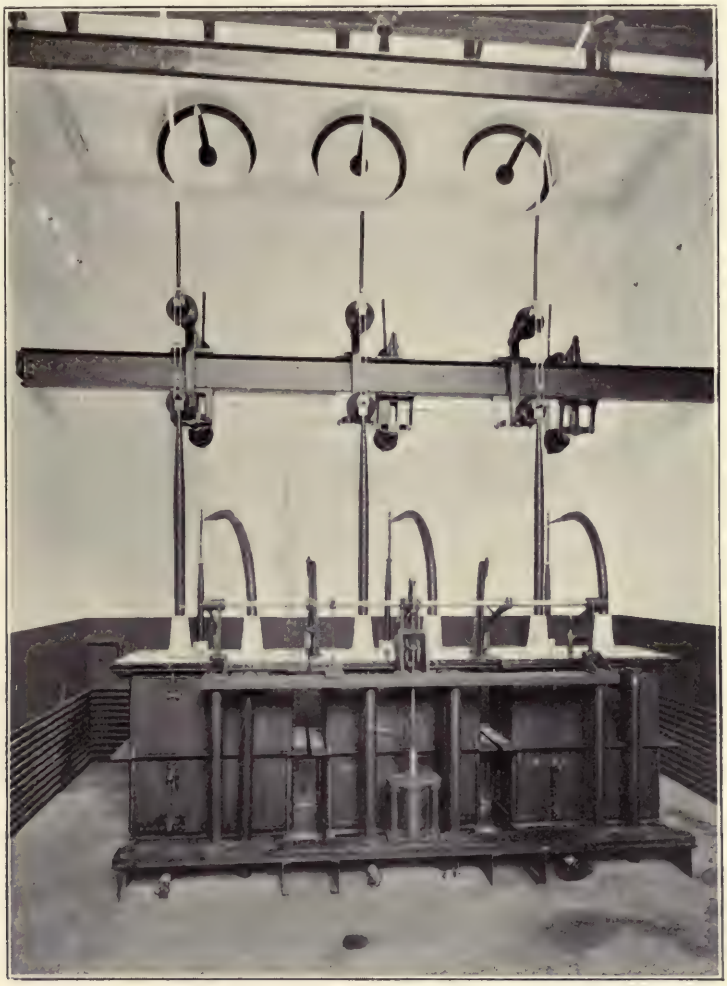


FIG. 4.—High Tension Oil Switch Compartment, Ontario Power Company.

have been installed in the 60,000-volt circuit of the Electrical Development Company of Toronto at Niagara Falls.

The top connected switches are usually solenoid operated, and the oil tanks are of sheet metal. The two stationary contacts forming each pole are located near the top of the oil, where sediment cannot settle. The contacts are separated by barriers,

[1] Switchboard Practice for Voltages of 60,000 and upwards, by S. Q. Hayes. Am. Inst. E. E., June, 1907.

as though each contact were in a separate tank. This type is usually installed without being encased in masonry compartments; however, the tanks and all the mechanism must be properly grounded for the protection of attendants. In the distributing

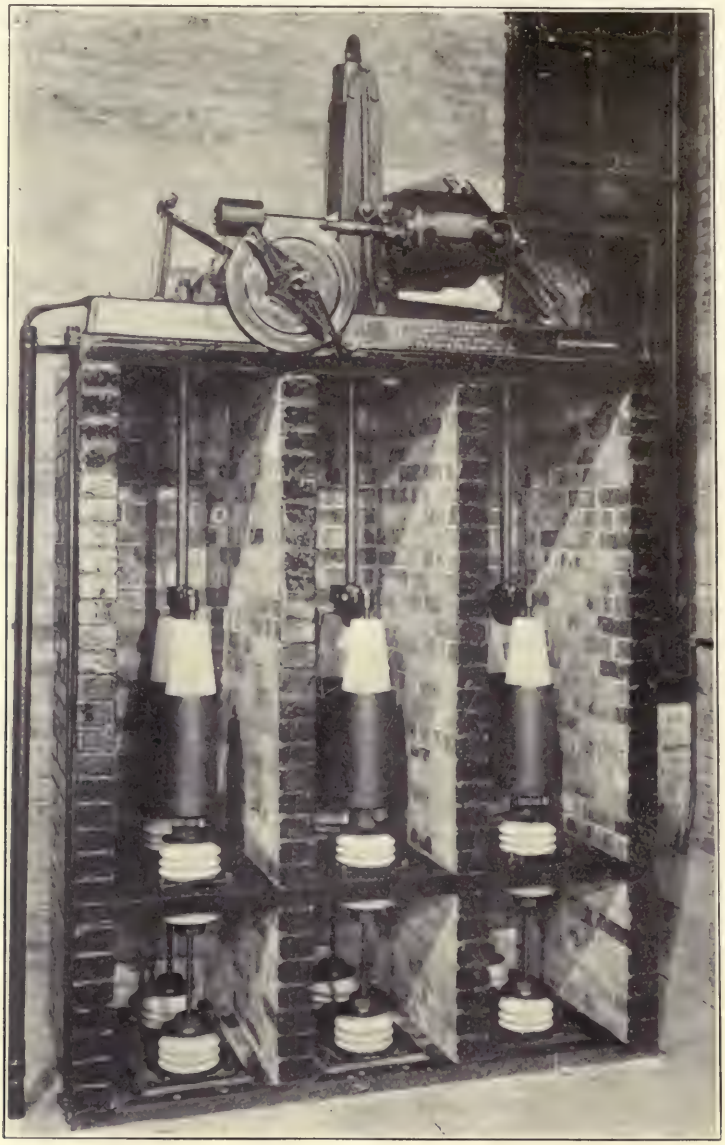


FIG. 5. — 30,000-volt, 50-ampere, Remote Motor Control, 3-pole Oil Switch, General Electric Company.

station of the Ontario Power Company types of this switch are installed for 62,000 volts. Both switches, of course, can be installed as circuit breakers, as practically all high tension switches have this provision, and can be arranged to work with a scheme of inclosed or open wiring. The bottom connected switch is essentially

designed for plants where the wiring, bus bars, etc., are placed in separate compartments, while the top connected breaker is designed for plants where the wiring is overhead.

Circuit Breakers. A high tension oil circuit breaker is nothing more than an oil switch provided with an automatic opening device. The purpose of the circuit

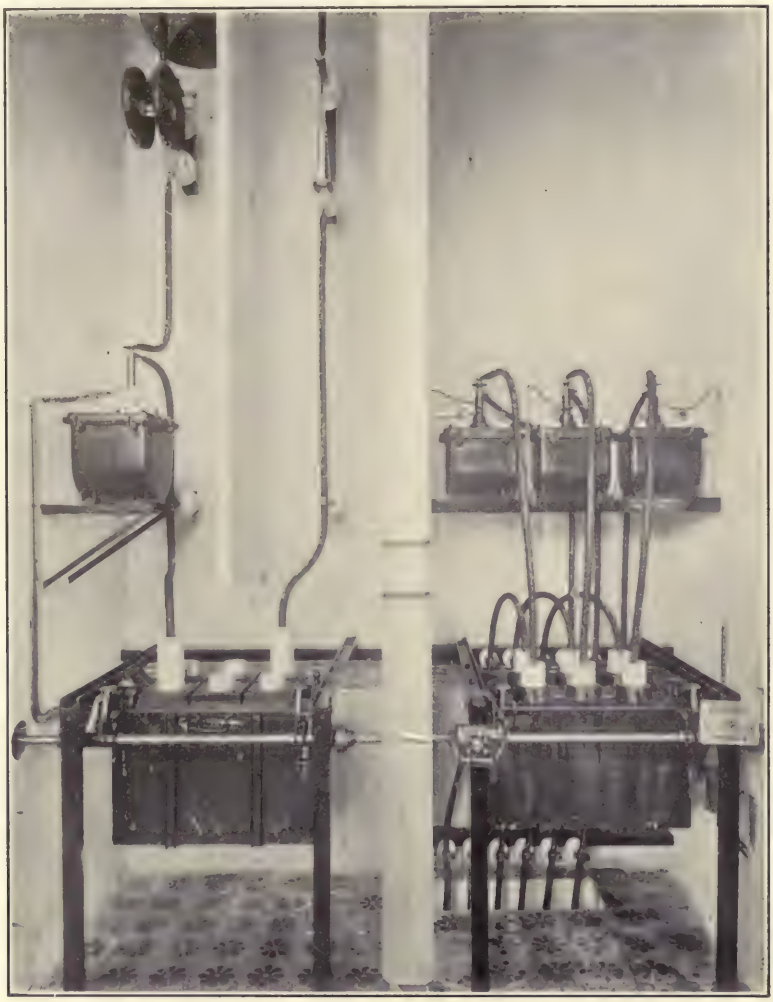


FIG. 6.—11,000 and 50,000-volt Switches and Substation, Castellanza, Italy.

breakers is to protect the generators and transformers from overloads, reversal of line current, and excess voltage, for which purpose (*a*) overload relays, (*b*) reverse current relays, (*c*) over-voltage relays, are installed.

(*a*) **Overload Relays.** Overloads in most cases are caused by short circuits on the line. The common practice is to maintain the short circuit and burn it out. There are cases, however, where the short circuit cannot be burned out, and to maintain it would damage the line. To prevent long and excessive shorts from

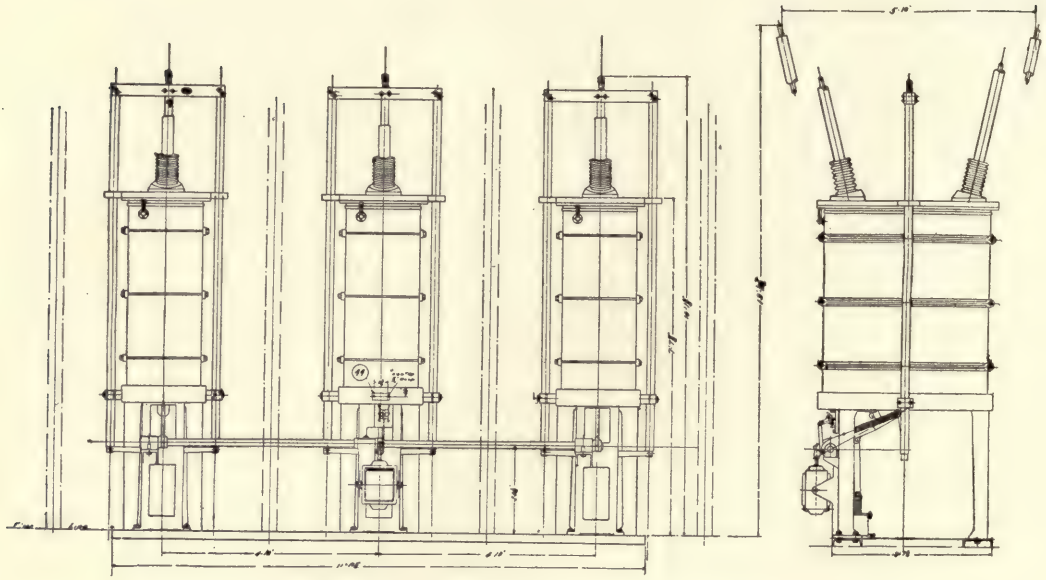


FIG. 7.—88,000-volt Top-connected Circuit Breaker with Sheet-Metal Tanks.

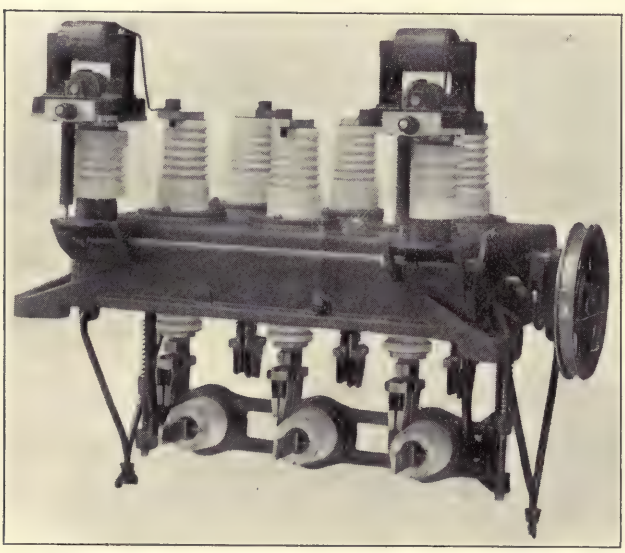


FIG. 8.—Siemens-Schuckert 35,000-volt Remote Control Switch with two Current Blowouts. Oil Tank removed.

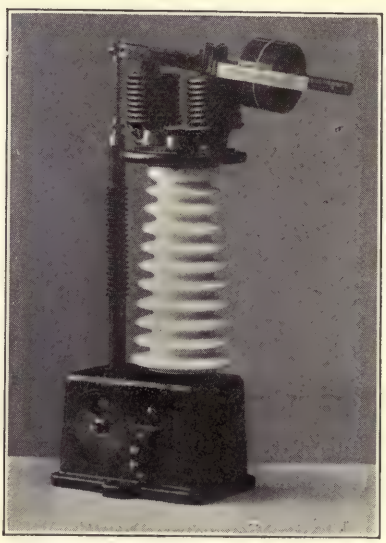


FIG. 9.—Siemens-Schuckert High Tension Time Relay.

damaging the line, the circuit breakers are provided with an overload relay, which will cause them to open in a certain set time after the short is established. The time varies usually from one to five seconds, depending upon the setting of the time limit of the relay.

(*b*) **Reverse Current Relays.** The reversals of current are caused chiefly by synchronous apparatus connected on the line, such as synchronous motors and rotary converters. Cases sometimes arise that these machines instead of absorbing power will pump it back, and when this happens there is usually trouble, especially if there are underground conduits in the system. To prevent any damage from this source, the power house circuit breakers are provided with reverse current relays, which cause the breaker to open upon reversal of line current.

(*c*) **Overload Voltage Relays.** The over-voltage relay causes the breaker to open upon excess of normal voltage, due to over-excitation or poor line regulation. The former difficulty is under the control of the operator, while the latter is under the control of the designing engineer and may be eliminated. These relays are not extensively used on high tension systems.

BIBLIOGRAPHY.

THE THEORY AND CALCULATION OF ALTERNATING CURRENT PHENOMENA. Charles P. Steinmetz. 1908.

GENERAL LECTURES ON ELECTRICAL ENGINEERING. Charles P. Steinmetz. 1908.

ALTERNATING CURRENT ENGINEERING PRACTICALLY TREATED. E. B. Raymond. 1905.

ALTERNATING CURRENT MACHINERY. William Esty. 1907.

ALTERNATING CURRENT MACHINES. Samuel Sheldon and H. Mason. 1908.

EXPERIMENTS WITH ALTERNATING CURRENT OF HIGH POTENTIAL AND HIGH FREQUENCY. N. Tesla. 1904.

HIGH SPEED ELECTRICAL MACHINERY. H. M. Hobart and A. G. Ellis. 1908.

DYNAMOS, MOTORS, ALTERNATORS, AND ROTARY CONVERTERS. G. Knapp. 1902.

POLYPHASE ELECTRIC CURRENTS AND ALTERNATE-CURRENT MOTORS. S. P. Thompson. 1903.

THE INSULATION OF ELECTRIC MACHINERY. H. Turner and H. M. Hobart. 1907.

PRACTICAL DYNAMO AND MOTOR CONSTRUCTION. A. W. Marshall. 1907.

ELEMENTARY PRINCIPLES OF CONTINUOUS-CURRENT DYNAMO DESIGN. H. M. Hobart and H. F. Parshall. 1908.

THE MANAGEMENT OF ELECTRICAL MACHINERY. F. B. Crocker and S. S. Wheeler. 1907.

DYNAMO-ELECTRIC MACHINERY. F. B. Crocker. 1907.

TROUBLES OF CENTRAL STATION SWITCHING APPARATUS AND METHODS OF HANDLING THEM. C. F. Conrad. *Electrical World*, Aug. 1, 1908.

EXTRA-HIGH-PRESSURE IRONCLAD SWITCHGEAR. *Electrical Review*, London, July 24, 1908.

METER AND RELAY CONNECTIONS. H. W. Brown. *Electric Journal*, May, 1908.

SWITCHING APPARATUS AND ITS PRACTICAL OPERATION IN LARGE HYDRO-ELECTRIC STATION. Frank E. Conrad. *Electrical World*, July 25, 1908.

OPERATION OF LARGE HYDRO-ELECTRIC STATION SWITCHING APPARATUS. F. E. Conrad. *Electrical World*, May 30, 1908.

SOME FEATURES OF EUROPEAN HIGH-TENSION PRACTICE. Frank Koester. *Electrical Age*, December, 1908.

SWITCHBOARD PRACTICE FOR VOLTAGES OF 60,000 AND UPWARD. Stephen Q. Hayes. *Pro. Am. Inst. E. E.*, June, 1907.

PART II.

THE TRANSMISSION OF HIGH TENSION ELECTRICAL CURRENT.

PART II.

THE TRANSMISSION OF HIGH TENSION ELECTRICAL CURRENT.

CHAPTER VIII.

ELECTRICAL TRANSMISSION.

A TRANSMISSION line should run at low levels and near highways, to facilitate erection, inspection and repair; it must further be borne in mind that the line must be as straight and short as possible, to minimize first cost, maintenance, line loss, and the expenditure for securing the right of way. Where the line runs through mountainous countries, high peaks must be avoided, because the temperature range between peak and valley is great and atmospheric electrical discharges are frequent. It is therefore better policy to détour the line than be troubled with atmospheric discharges.

For high-tension lines, two separate circuits must be run either on a common or two separate towers, so that one is always in reserve. Such lines must be divided up into sections, provided with section switches and by-pass connections, so that a continuity of service is assured. The sections may be about 20 miles long, and at the end of each section must be a repair shop and accommodations for the patrolman, whose duty is to inspect the section once or twice a day. All poles and towers must be properly numbered to facilitate the location of trouble.

Telephone connections must be established at the patrolman's quarters and at frequent intervals. For further convenience, portable telephones may be used. The telephone line, in duplicate, is best run on separate poles, and is also used for telegraph purposes. These lines must be for the exclusive use of the transmission company.

TRANSMISSION CONDUCTORS.

Strength of Conductors. Aerial lines transmit the electrical energy from hydraulic plants to the center of distribution. The material used for conductors is copper, hard or soft drawn, aluminum and steel; all three are used in cable form, while copper is sometimes used as solid conductor.

For transmission purposes, hard drawn copper is almost always used, as it has an ultimate tensile strength of 60,000 pounds per square inch, while that of soft drawn copper is only 30,000 pounds. The resistance of the former is 5 per cent greater than that of the latter. Aluminum has a tensile strength of about 28,000 pounds; while steel varies greatly, it averages 100,000 pounds.

Elasticity of Conductors. The elasticity of a cable is much greater than that of a solid wire, therefore cables are preferable for long-span transmission lines.

TABLE I. — MODULUS OF ELASTICITY.

Copper wire, hard drawn	19,500,000
Copper, hard drawn cable strand	16,300,000
Aluminum, hard drawn	10,200,000
Steel wire	28,000,000

TABLE II. — COEFFICIENT OF EXPANSION PER DEGREE FAHRENHEIT.

Copper	0.0000096
Aluminum	0.0000130
Steel	0.0000064

From the tables it will be seen that steel cables compare very favorably for long spans, but the disadvantage is the low conductivity, being only 12, while that of copper is 100.

Cables as Conductors. The strands in a cable must be continuous, to give it uniform strength and conducting area. The lengths of cable obtainable are longer than those of a solid conductor, for the reason that a cable is made up of a number of small strands, each of which is made from the same-sized ingot as a larger conductor. The weights of cables are calculated about one per cent heavier than a solid wire of the same circular millage, while the resistance is calculated for a solid conductor. The number (n) of strands in a cable of given circular millage (C.M.), composed of wires of diameter (d), is found by the following formula:

$$\text{C.M.} = d^2 \times n.$$

$$n = \frac{\text{C.M.}}{d^2}.$$

$$d = \sqrt{\frac{\text{C.M.}}{n}}.$$

The diameter of a cable is found by multiplying the diameter of one wire by the factors given in Table III, according to the number of strands composing the cable. Another convenient table on this subject is found in the appendix.

TABLE III. — STRAND FACTOR.

Number of strands	Factor.
3	2.25
7	3.00
12	4.25
19	5.00
27	6.25

Spacing of Conductors. The spacing of conductors depends on the voltage and on the length of the spans, and varies from 24 to 96 inches. The increase in spacing increases the inductive drop, and also the line loss. There are no fixed rules established for the spacing of conductors. The following are approximate distances: for voltages from 5000 to 10,000, 24 to 36 inches; for 10,000 to 30,000, 36 to 60 inches; for 30,000 to 60,000, 60 to 84 inches; for 60,000 to 100,000 and higher, from 84 to 96 inches.

Characteristics of Conductors. Comparing the specific gravities of aluminum and copper, the latter is about 3.3 times greater than the former, so that for cables of equal length and resistance, the copper cable is twice as heavy as the aluminum. As the tensile strength is only about 28,000 pounds per square inch, aluminum wires must be used only in the form of a cable. For equivalent conditions, the diameter of an aluminum cable is 1.28 times that of copper, while the cross-sectional area is about 1.65 times larger, because the conductivity of aluminum is only 63 per cent that of copper. Cables present a larger surface to the wind, and also, for the formation of ice. The advantages gained in the use of aluminum are, cheaper than copper and light weight, which in turn reduces the cost of pole line construction. Owing to the high coefficient of expansion, aluminum wires must be strung either in the spring or fall, preferably the latter. Heretofore, much difficulty was experienced in splicing cables of aluminum; this has been overcome in recent practice.

According to the laws of transformation of alternating currents, the higher the voltage, the smaller the current for a given amount of power, and vice versa. So far as the transmission line itself is concerned, the highest voltage which can commercially be produced, is the best voltage. A small current on the line means that the size of wire can be reduced until the mechanical strength of the wire predominates. The use of high voltages reduces the line drop, losses in transmission, and gives better regulation than low voltages.

Size of Conductors. The essential factors necessary for calculating the size of line conductors are: the load to be transmitted, the voltage desired at the receiving end, the permissible loss of energy in transmission, the frequency, spacing of the wires on the cross-arms, length of transmission line.

The size of conductors is, for standard sizes, usually designated by a number; for sizes larger, they are designated by their cross-sectional area in circular mils. The largest standard size is 0000 and is 0.46 of an inch in diameter.

The circular mil is the thousandth part of an inch, and is chosen as the unit of measurement for electrical conductors. Thus the diameter of a one-inch cable is 1000 mils, and its area is a million circular mils or $(1000)^2$ circular mils.

In calculating the size of transmission conductors it is poor policy to use a larger conductor than is absolutely necessary. This fact is well illustrated in a law developed by Lord Kelvin, and known by that name. The usual way of stating it is: " The most economical area of conductor will be that for which the annual interest on the capital outlay equals the annual cost of the energy wasted." A more precise statement of the same thing is given by Gisbert Kapp,[1] " The most economical area of conductor is that for which the annual cost of the energy wasted is equal to the interest on that portion of the capital outlay which can be considered to be proportional to the weight of the metal used."

Direct Current Conductors. For calculating the size of conductors for direct current distribution the following formulas suffice:

$$I = \frac{\text{K.W.} \times 1000}{E}.$$

$$\frac{2 \times D \times I \times 11}{E \times p} = \text{size of conductor in circular mils.}$$

K.W. = load in kilowatts.
I = current.
E = voltage.
D = distance one way in feet.
11 = resistance of copper per mil-foot.
p = percentage drop in voltage.

Direct Current Problem. For example, it is desired to transmit 500 K.W. at 500 volts for a distance of two miles with a line drop of 10 per cent.

$$2 \text{ miles} = 5280 \times 2 = 10{,}560 \text{ ft.}$$

Then
$$I = \frac{500 \times 1000}{500} = 1000 \text{ amp.}$$

$$\text{C.M.} = \frac{2 \times 10{,}560 \times 1000 \times 11}{500 \times 0.10} = 4{,}646{,}400.$$

Upon consulting the wire tables it will be seen that this is not of standard size, in fact it is a little less than 22 wires of No. 0000, the largest standard size.

Suppose 22 wires were used. The resistance of the whole circuit is one twenty-second of one circuit of No. 0000. The resistance of No. 0000 is about 0.05 ohm per 1000 feet. The resistance for the whole is $2 \times 10.56 \times .05 \div 22 = 0.048$ ohm.

To check up results on this assumption,

$$\text{Voltage drop} = 0.048 \times 1000 = 48 \text{ volts.}$$

$$\frac{48}{500} \times 100 = 9.6 \text{ per cent, line drop.}$$

$$(1000)^2 \times 0.048 \div 1000 = 48 \text{ K.W., line loss.}$$

$$48 \div 500 \times 100 = 9.6 \text{ per cent, energy loss in transmission.}$$

[1] Economical Conductor Section, by Frank G. Baum. *Electrical World*, May 25, 1907.

A.E.&M

If in the above calculations the voltage be doubled, the size of the wire will be only one-quarter as great; that is, the amount of copper varies inversely as the square of the voltage.

Alternating Current Conductor. In the calculations of alternating currents new factors have to be taken into consideration, and their value depends upon the frequency and the distance the wires are apart, etc. In direct current transmission the losses can be calculated either $E \times I$ or I^2R, but in alternating current only I^2R gives the real loss; $E \times I$ gives the apparent loss.

Alternating Current Problem. For single phase transmission the following example gives approximate results. Suppose a load 1000 K.W. is to be received at a distance of ten miles at 10,000 volts, frequency 25 cycles, power factor 0.85, line loss 10 per cent, wires spaced 36 inches apart.

$$1000 \text{ K.W.} = \text{actual energy.}$$

$$1000 \div 0.85 = 1176.4 \text{ K.W., apparent energy.}$$

$$1176.4 \times 1000 \div 10{,}000 = 117.64 \text{ amperes.}$$

$$I^2R = (117.64)^2R = \text{line loss.}$$

Also $1000 \text{ K.W.} \times 10 \text{ per cent} = 100 \text{ K.W., line loss.}$

Then $(117.64)^2 \times R = 100 \times 1000.$

$$R = \frac{100 \times 1000}{(117.64)^2} = 7.23 \text{ ohms (total).}$$

$$\text{Resistance per 1000 feet} = \frac{7.23 \times 1000}{2 \times 10 \times 5280} = 0.0684 \text{ ohm.}$$

This corresponds nearly to a No. 00 wire, which has a resistance of 0.076 ohms per 1000 feet.

The resistance of the circuit with No. 00 is

$$5.280 \times 2 \times 10 \times 0.076 = 8.02 \text{ ohms.}$$

$$117.6 \times 8.02 = 941 \text{ volts; resistance volts.}$$

To calculate the drop due to reactance, recourse to Table VII is necessary. It represents the reactance volts per ampere per 1000 feet of line (2000 feet of wire) at 60 cycles. For distances not given in the tables interpolations are made directly. From the table the constant for No. 00 placed at 36 inches is 0.254. This is the drop per ampere at 60 cycles. As this value varies directly with the frequency, for 25 cycles the reactance volts are

$$105.6 \text{ (thousands of feet)} \times 117.6 \times 0.254 \times \frac{25}{60} = 1314.$$

The line drop is not current $\times$ resistance, but

$$\sqrt{(941)^2 + (1314)^2} = 1597.$$

$1597 \div (10{,}000 + 1597) \times 100 = 13.77$ per cent, drop in generator station voltage.

$(117.6)^2 \times 8.02 \div 1000 = 17.24$ K.W., line loss.

$17.24 \div (1000 + 17.24) \times 100 = 16.9$ per cent, loss of energy in transmission.

TABLE IV. — COMPARISON OF WIRE GAUGES.

No.	A. W. G. Brown & Sharpe. (B. & S. G.)		Stubs. Birmingham. (B. W. G.)		(N. B. S.) English Standard. (S. W. G.)		A. S. & W. Co. Washburn & M. Roebling's.	
	Diam. Mils.	Cir. Mils.	Diam. Mils.	Cir. Mils.	Diam. Mils.	Cir. Mils.	Diam. Mils.	Cir. Mils.
000000	580.00	336,400	.....	.....	464	215,296	460	211,600
00000	516.50	266,772	.....	.....	432	186,624	430	184,900
0000	460.00	211,600	454	206,116	400	160,000	394	154,764
000	409.64	167,805	425	180,625	372	138,384	363	131,406
00	364.80	133,079	380	144,400	348	121,104	331	109,561
0	324.86	105,534	340	115,600	324	104,976	307	94,249
1	289.30	83,694	300	90,000	300	90,000	283	80,089
2	257.63	66,373	284	80,656	276	76,176	263	69,169
3	229.42	52,633	259	67,081	252	63,504	244	59,536
4	204.31	41,742	238	56,644	232	53,824	225	50,625
5	181.94	33,102	220	48,400	212	44,944	207	42,849
6	162.02	26,250	203	41,209	192	36,864	192	36,864
7	144.28	20,817	180	32,400	176	30,976	177	31,329
8	128.49	16,509	165	27,225	160	25,600	162	26,244
9	114.43	13,094	148	21,904	144	20,736	148	21,904
10	101.89	10,381	134	17,956	128	16,384	135	18,225
11	90.742	8,234.1	120	14,400	116	13,456	121	14,520
12	80.808	6,529.9	109	11,881	104	10,816	106	11,130
13	71.964	5,178.4	95	9,025	92	8,464	92	8,464
14	64.084	4,106.8	83	6,889	80	6,400	80	6,400
15	57.068	3,256.8	72	5,184	72	5,184	72	5,184
16	50.820	2,582.7	65	4,225	64	4,096	63	3,969
17	45.257	2,048.2	58	3,364	56	3,136	54	2,916
18	40.303	1,624.3	49	2,401	48	2,304	48	2,256
19	35.890	1,288.1	42	1,764	40	1,600	41	1,681
20	31.961	1,021.5	35	1,225	36	1,296	35	1,225
21	28.462	810.08	32	1,024	32	1,024	32	1,024
22	25.347	642.47	28	784	28	784	29	818
23	22.571	509.45	25	625	24	576	26	666
24	20.100	404.01	22	484	22	484	23	529

N. B. — S. W. G. has No. 0000000; diameter, 500 mils; area, 250,000 cir. mils.

TABLE V. — SOLID COPPER WIRE.

BARE AND INSULATED.

No. B. & S.	Diam. Mils.		Area. Cir. Mils.	Weight, pounds.				Resistance. Int. Ohms, 20° C. (68° F.)–Matt. Std.		Carrying capacity. Amp.	
				Bare.		T. B. Weatherproof.				16° F. rise, concealed.	32° F. rise, open.
	Bare.	T. B. Weather proof.		1000′.	Mile.	1000′.	Mile.	1000′.	Mile.		
0000	460	780	211,600	640.5	3,381	754	3,980	.04893	.2583	210	312
000	409.6	700	167,805	508.0	2,682	614	3,240	.06170	.3258	177	262
00	364.8	635	133,079	402.8	2,127	486	2,570	.07780	.4108	150	220
0	324.9	590	105,534	319.5	1,687	388	2,050	.09811	.5180	127	185
1	289.3	550	83,694	253.3	1,337	312	1,650	.12370	.6531	107	156
2	257.6	515	66,373	200.9	1,062	254	1,340	.1560	.8237	90	131
3	229.4	450	52,633	159.3	841.1	201	1,060	.1967	1.0386	76	110
4	204.3	430	41,742	126.4	667.4	163	860	.2480	1.3094	65	92
5	181.9	400	33,102	100.2	529.0	134	710	.3128	1.6516	54	77
6	162.0	360	26,250	79.46	419.5	112	590	.3944	2.0824	46	65
7	144.3	335	20,817	63.02	332.7	89	470	.4973	2.6257	39	55
8	128.5	280	16,509	49.98	263.9	73.8	390	.6271	3.3111	33	46
9	114.4	255	13,094	39.63	209.2	60.6	320	.7908	4.1754	28	38
10	101.9	220	10,381	31.43	166.0	50.2	265	.9972	5.2652	24	32
11	90.74	205	8,234	24.93	131.6	42.6	225	1.257	6.6370	20	27
12	80.81	185	6,530	19.77	104.4	35.0	185	1.586	8.374	17	23
13	71.96	170	5,178	15.68	82.79	30.3	160	1.999	10.560	14	19
14	64.08	160	4,107	12.43	65.63	25.9	137	2.521	13.311	12	16
15	57.07	155	3,257	9.858	52.05	22.7	120	3.179	16.785	9	12
16	50.82	150	2,583	7.818	41.28	19.9	105	4.009	21.168	6	8
17	45.26	147	2,048	6.200	32.74	18.0	95	5.055	26.690	4.5	6.5
18	40.30	145	1,624	4.917	25.96	16.1	85	6.374	33.655	3	5
19	35.89	140	1,288	3.899	20.59	14.2	75	8.038	42.440	2.3	4
20	31.96	135	1,022	3.092	16.33	12.3	65	10.14	53.540	1.5	3
	A.I.E.E.	S.U.C.C.	A. I. E. E.			Average.[1]		A. I. E. E.		Nat. Elec. Code.	

[1] Std. Und. Cable Co., J. A. Roebling's Co., Amer. Elec. Works, Gen. Elec. Co., Amer. St. & W. Co., Hazard Mfg. Co.

TABLE VI. — STRANDED COPPER WIRE.

BARE AND INSULATED.

No. and Diam. of Strands or Size B. & S.	Diam. Mils.		Area. Cir. Mils.	Weight, pounds.				Resistance. Int. Ohms, 20° C. (68° F.) Matt. Std.		Carrying capacity. Amperes.	
				Bare.		T. B. Weatherproof.					
	Bare.	T. B. Weather-proof.		1000′.	Mile.	1000′.	Mile.	1000′.	Mile.	16° F. rise, con-cealed.	32° F. rise, open.
91/.128	1,408	1,875	1,500,000	4,575	24,156	5,335	28,169	.006902	.03644	850	1,360
91/.117	1,287	1,775	1,250,000	3,813	20,132	4,450	23,496	.008282	.04373	750	1,185
61/.128	1,152	1,635	1,000,000	3,050	16,104	3,610	19,061	.010353	.05466	650	1,000
61/.125	1,125	1,600	950,000	2,898	15,299	3,450	18,216	.010900	.05755	625	960
61/.121	1,092	1,525	900,000	2,745	14,494	3,268	17,255	.01150	.06072	600	920
61/.118	1,062	1,500	850,000	2,593	13,688	3,083	16,278	.01218	.06431	575	880
61/.115	1,035	1,475	800,000	2,440	12,883	2,905	15,338	.01294	.06832	550	840
61/.111	999	1,425	750,000	2,288	12,078	2,730	14,415	.01380	.07286	525	800
61/.107	963	1,405	700,000	2,135	11,273	2,569	13,565	.01479	.07809	500	760
61/.103	927	1,375	650,000	1,983	10,468	2,393	12,635	.01593	.08411	475	720
61/.099	891	1,350	600,000	1,830	9,662	2,215	11,695	.01725	.09108	450	680
61/.095	855	1,300	550,000	1,678	8,857	2,040	10,771	.01882	.09937	420	635
61/.091	819	1,250	500,000	1,525	8,052	1,870	9,875	.02070	.10930	390	590
37/.110	770	1,200	450,000	1,373	7,247	1,694	8,945	.02300	.12144	360	545
37/.104	728	1,190	400,000	1,220	6,442	1,529	8,075	.02588	.13664	330	500
37/.097	679	1,125	350,000	1,068	5,636	1,320	6,970	.02958	.15618	300	450
37/.090	630	955	300,000	915	4,831	1,133	5,982	.03451	.18221	270	400
37/.083	590	920	250,000	762	4,026	940	4,963	.04141	.21864	235	350
0000 B &S	530	805	211,600	641	3,381	779	4,115	.04893	.2583	210	312
000 "	470	750	167,805	508	2,682	650	3,432	.06170	.3258	177	262
00 "	420	660	133,079	403	2,127	527	2,785	.07780	.4108	150	220
0 "	375	615	105,534	320	1,687	430	2,270	.09811	.5180	127	185
1 "	330	575	83,694	253	1,337	326	1,722	.12370	.6531	107	156
2 "	291	535	66,373	201	1,062	270	1,426	.15600	.8237	90	131
3 "	261	475	52,633	159	841	218	1,150	.19670	1.0386	76	110
4 "	231	415	41,742	126	667	176	930	.2480	1.3094	65	92
	Haz. M.C.	J.A R	Haz. M.C.	A I.E.E.		J. A. Roebling's		Haz. Mfg. Co.		A. I. E. E.	Nat. Elec. Code

TABLE VII. — REACTANCE VOLTS.

Size of Conductor.	Distance apart of conductors in inches.						
	12-inch.	18-inch.	24-inch.	30-inch.	36-inch.	48-inch.	96-inch
0000	.193	.212	.225	.235	.244	.251	.283
000	.199	.217	.230	.241	.249	.255	.287
00	.204	.222	.236	.246	.254	.262	.294
0	.209	.228	.241	.251	.259	.267	.299
1	.214	.233	.246	.256	.265	.273	.305
2	.220	.238	.252	.262	.270	.277	.309
3	.225	.244	.257	.267	.275	.282	.314
4	.230	.249	.262	.272	.281	.294	.326
5	.236	.254	.268	.278	.286	.299	.331
6	.241	.260	.272	.283	.291	.305	.337
7	.246	.265	.278	.288	.296	.310	.342
8	.252	.270	.284	.293	.302	.315	.347

TABLE VIII. — WEIGHT AND STRENGTH OF ELECTRICAL WIRES.

No. B. & S.	Weight. — Pounds per 1000 feet (bare).				Breaking weight. — Pounds.					
	Copper & Phono-Elec.	Alum-inum.	Wrought Iron.	Steel.	Copper, Hard.	Copper, Soft.	Phono-Electric.	Alum-inum.	Charcoal Iron, Bright	Crucible Steel, Ordinary
0000	640.5	192.86	553.97	565.50	8,310	5,650	11,460	4,150	13,000	16,250
000	508.0	152.94	439.33	448.45	6,580	4,480	9,140	3,290	10,400	13,000
00	402.8	121.28	348.40	355.65	5,226	3,553	7,400	2,620	8,350	10,430
0	319.5	96.18	276.30	282.02	4,558	2,818	6,300	2,070	6,650	8,300
1	253.3	76.29	219.11	223.68	3,746	2,234	5,250	1,640	5,450	6,810
2	200.9	60.50	173.78	177.38	3,129	1,772	4,180	1,300	4,300	5,370
3	159.3	47.97	137.80	140.67	2,480	1,405	3,360	1,030	3,550	4,430
4	126.4	38.05	109.28	111.57	1,967	1,114	2,700	819	2,850	3,560
5	100.2	30.17	86.68	88.46	1,559	883	2,080	650	2,300	2,875
6	79.5	23.93	68.73	70.15	1,237	700	1,680	515	1,850	2,310
7	63.0	18.98	54.43	55.56	980	555	1,350	408	1,500	1,875
8	50.0	15.05	43.23	44.12	778	440	1,075	324	1,200	1,500
9	39.6	11.93	34.28	34.99	617	349	850	255	970	1,210
10	31.4	9.46	27.18	27.74	489	277	685	204	765	955
11	24.9	7.51	21.56	22.01	388	219	545	162	610	762
12	19.8	5.95	17.10	17.46	307	174	420	128	490	612
13	15.7	4.72	13.56	13.84	245	138	340	103	395	493
14	12.4	3.74	10.75	10.98	193	109	270	84	315	394
15	9.9	2.97	8.53	8.70	153	87	220	67	255	319
16	7.8	2.35	6.76	6.90	133	69	180	52	205	256
17	6.2	1.87	5.36	5.47	97	55	135	42	170	212
18	4.9	1.48	4.25	4.34	77	43	107	34	135	169
19	3.9	1.17	3.37	3.44	61	34	86	27	110	137
20	3.1	.93	2.67	2.73	48	27	70	21	90	112
	Weight.—Pounds per cubic inch.				Tensile strength. — Pounds per square inch.					
	.322	.0967	.278	.284	50,000 60,000	34,000	69,000 85,000	25,000 39,000	78,000 112,000	97,000 140,000
Authority	B. B. Co.	Pittsburgh Reduction Co.			Bridgeport Brass Co.			P. R. Co.	Trenton Iron Co.	

TABLE IX. — AMERICAN AND ENGLISH STANDARD COPPER CABLE.

STRANDED, BARE.

American. B. & S.	English. No. and Diameter of Single Strands.	Diam. Cable.		Area.			Weight.		Resistance. — Int. Ohms.		
		Inch.	mm.	Sq. In.	Sq. mm.	Cir. Mil.	Lb. 1000ft.	Kilog. Kilom.	Matt. Std.–20° C. 1000 Ft.	Matt. Std.–20° C. Kilom.	60° F. 1000 Yd.
	7/.068	.204	5.18	**.025**	16.13	32,400	100	149	.320	1.050	.962
4	.....	.231	5.87	.0328	21.15	41,742	126	189	.2480	.814	.....
3	.....	.261	6.63	.0413	26.65	52,633	159	238	.1967	.6452	.....
	7/.095	.285	7.24	**.050**	32.30	63,150	193	287	.1640	.5380	.493
2	.....	.291	7.39	.0521	33.65	66,373	201	302	.1560	.5119	.....
1	.....	.330	8.38	.0657	42.40	83,694	253	380	.1237	.4058	.....
	19/.072	.360	9.14	**.075**	48.40	98,500	304	453	.1051	.3446	.317
0	.....	.375	9.52	.0829	53.48	105,534	320	479	.09811	.3220	.....
	19/.082	.410	10.41	**.100**	64.52	127,800	394	586	.08100	.2655	**.244**
00	.....	.420	10.67	.1045	67.50	133,079	403	605	.07780	.2552	.....
	19/.092	.460	11.68	**.125**	81.50	160,800	496	738	.06440	.2112	.194
000	.....	.470	11.94	.132	85.00	167,805	513	766	.06170	.2024	.....
	19/.101	.505	12.83	**.150**	98.20	193,800	594	886	.05340	.1752	.161
0000	.....	.530	13.46	.166	107.2	211,600	645	960	.04893	.1606	.....
	37/.082	.574	14.59	**.200**	129.0	248,500	768	1,144	.04170	.1367	.125
250,000 cm.	.....	.590	14.99	.196	126.7	250,000	762	1,135	.04141	.1360	.....
300,000 "	.....	.630	16.00	.236	152.0	300,000	915	1,362	.03451	.1132	.....
	37/.101	.707	17.96	**.300**	194.0	377,200	1,165	1,735	.02748	.0901	.0827
400,000 "	.....	.728	18.50	.314	202.7	400,000	1,220	1,815	.02588	.0849	.....
500,000 "	.....	.819	20.80	.393	253.4	500,000	1,525	2,268	.02070	.0679	.....
	61/.092	.828	21.03	**.400**	258.5	516,000	1,591	2,372	.02008	.0662	.0605
600,000 "	.....	.891	22.63	.471	304.0	600,000	1,830	2,725	.01725	.0566	.....
	61/.101	.909	23.10	**.500**	323.0	622,000	1,921	2,860	.01666	.05468	.0502
700,000 "	.....	.963	24.48	.550	354.7	700,000	2,135	3,180	.01479	.04850	.....
	61/.110	.990	25.15	**.600**	388.0	738,000	2,279	3,390	.01403	.04602	.0423
800,000 "	.....	1.035	26.30	.628	405.4	800,000	2,440	3,630	.01294	.04250	.....
	91/.098	1.078	27.40	**.700**	452.0	874,000	2,698	4,015	.01185	.03888	.0357
	91/.104	1.144	29.06	**.800**	451.7	984,000	3,038	4,524	.01052	.03450	.0317
1,000,000 "	.....	1.152	29.25	.785	506.7	1,000,000	3,050	4,540	.01035	.03396	.....
	B	R–C	C	D–B–C	C	A–C	R–B	C	A	C	B

AUTHORITIES. — A—Amer. Inst. Elec. Eng.; B—Standard of Cable Makers' Ass., Feb. 5, 1903, England; C—Calculated from Strand or by Conversion; R—J. A. Roebling's Sons Co.; D—Heavy figures denote nominal English sizes, but check only approximately with other quantities.

TABLE X. — AMERICAN AND ENGLISH SOLID COPPER WIRE.

BARE, WITH ENGLISH AND METRIC MEASURES.

American. B. & S.	English. S. W. G.	Diameter.		Area.			Weight.		Resistance—20° C. Int. Ohms. (68°F.) Matthiessen's St'd.	
		Inch.	mm.	Sq. In.	Sq. mm.	Cir. Mils.	Pounds. 1000′.	Kilog. Kilom.	1000′.	Kilom.
.....	7–0	.5000	12.700	.1963	126.670	250,000	756	1126	.04141	.1360
.....	6–0	.4640	11.785	.1691	109.090	215,296	651	968	.04805	.1576
0000	.....	.4600	11.683	.1662	107.100	211,600	641	955	.04893	.1605
.....	5–0	.4320	10.972	.1466	94.560	186,624	565	840	.05550	.1820
000	.....	.4096	10.404	.1318	85.000	167,805	508	756	.06170	.2025
.....	0000	.4000	10.160	.1257	81.070	160,000	484	721	.06472	.2123
.....	000	.3720	9.448	.1087	70.120	138,384	419	623	.07481	.2453
00	.....	.3648	9.266	.1045	67.400	133,079	403	600	.07780	.2552
.....	00	.3480	8.839	.0951	61.360	121,104	366	545	.08550	.2804
0	.....	.3249	8.251	.0829	53.400	105,534	320	476	.09811	.3220
.....	0	.3240	8.229	.0825	53.190	104,976	317	472	.09870	.3240
.....	1	.3000	7.620	.0707	45.600	90,000	272	405	.1151	.3773
1	.....	.2893	7.348	.0657	42.360	83,694	253	377	.1237	.4059
.....	2	.2760	7.010	.0598	38.600	76,176	230	343	.1361	.4465
2	.....	.2576	6.544	.0521	33.600	66,373	201	299	.1560	.5116
.....	3	.2520	6.401	.0499	32.176	63,504	192	286	.1631	.5348
.....	4	.2320	5.893	.0423	27.272	53,824	163	243	.1925	.6313
3	.....	.2294	5.827	.0413	26.650	52,633	159	237	.1967	.6450
.....	5	.2120	5.385	.0353	22.772	44,944	136	203	.2308	.757
4	.....	.2043	5.190	.0328	21.150	41,742	126	188	.2480	.813
.....	6	.1920	4.877	.0290	18.678	36,864	111	165	.2812	.922
5	.....	.1819	4.621	.0260	16.770	33,102	100	149	.3128	1.026
.....	7	.1760	4.470	.0243	15.659	30,976	93.7	139	.3346	1.098
6	.....	.1620	4.115	.0206	13.350	26,250	79.5	118	.3944	1.294
.....	8	.1600	4.064	.0201	13.035	25,600	77.5	115	.4050	1.329
7	9*	.1443	3.665	.0164	10.440	20,817	63.0	93.9	.4973	2.632
8	10*	.1285	3.263	.0130	8.367	16,509	50.0	74.4	.6271	2.058
....	11	.1160	2.947	.0100	6.818	13,456	40.7	60.6	.7700	2.525
9	.....	.1144	2.906	.0103	6.580	13,094	39.6	59.0	.7908	2.592
.....	12	.1040	2.641	.00850	5.480	10,816	32.8	48.8	.9570	3.140
10	.....	.1019	2.588	.00815	5.250	10,381	31.4	46.7	.9972	3.270
.....	13	.0920	2.337	.00665	4.288	8,464	25.6	38.1	1.226	4.020
11	.....	.0907	2.305	.00646	4.168	8,234	24.9	37.1	1.257	4.124
12	14*	.0808	2.052	.00513	3.308	6,530	19.8	29.5	1.586	5.200
13	15*	.0720	1.828	.00407	2.626	5,178	15.7	23.3	1.999	6.560
14	16*	.0641	1.628	.00323	2.083	4,107	12.4	18.5	2.521	8.260
15	.....	.0571	1.449	.00256	1.652	3,257	9.86	14.7	3.179	10.42
.....	17	.0560	1.422	.00246	1.590	3,136	9.49	14.1	3.305	10.84
16	.....	.0508	1.291	.00203	1.310	2,583	7.82	11.6	4.009	13.15
.....	18	.0480	1.219	.00181	1.167	2,304	6.97	10.4	4.496	14.74
17	.....	.0453	1.150	.00161	1.039	2,048	6.20	9.22	5.055	16.59
18	19*	.0403	1.024	.00128	.823	1,624	4.92	7.30	6.374	20.90
19	20*	.0359	.9116	.00101	.653	1,288	3.90	5.79	8.038	26.36
20	21*	.0320	.8118	.00080	.517	1,022	3.09	4.60	10.14	33.25
21	.....	.0285	.7229	.000638	.412	810	2.45	3.65	12.78	41.90
.....	22	.0280	.7112	.000615	.397	784	2.40	3.57	13.21	43.30
22	.....	.0254	.6438	.000507	.327	643	1.95	2.89	16.12	52.8
.....	23	.0240	.6096	.000452	.291	576	1.70	2.53	18.00	59.0
23	24*	.0226	.5733	.000401	.258	510	1.54	2.29	20.32	66.7
24	25*	.0201	.5105	.000317	.204	404	1.22	1.82	25.63	84.0

* Approximate English Equivalents to American sizes.

The size of wire chosen shows that the line loss is greater than the regulation, which is impractical. As this is a cut and try method, such conditions appear only in checking assumptions. This is corrected by using No. 000, instead of No. 00, which was tried in this calculation.

If the transmission is to be two phase, the calculations are similar except that each phase carries half of the power.

For three phase, calculate for a single phase to carry half of the power, and each wire is the size determined.

Transposition. Excessive inductive effects can be counteracted by transposing the conductors. In the final transposition the phases must occupy the same relative position as at the beginning. The number of transpositions is arbitrary; for instance, the 52,000-volt line, Gaucin-Seville, Spain, has 35 transpositions throughout its length of 75 miles, while the 50,000-volt line from the Uppenborn plant to the city of Munich, Germany, has but three transpositions in its run of 33 miles.

Corona Effect. When two conductors in the neighborhood of each other are charged with a very high potential, and after a certain value of electrical pressure has been reached, a bluish glow surrounds the conductors; this glow is distinctly visible in the dark. Coincidently with the appearance of this glow, loss of power begins. A further increase in electromotive force produces a brush discharge, which takes place, not from surface of the conductor, but from the external limits of the luminous envelope surrounding the conductor. This brush discharge results in further augmentation of electrical losses, and is usually accompanied by a hissing or crackling noise. It is intermittent in character and is reddish violet in color. The name "corona" has been given to the combined luminous manifestations of initial glow and subsequent brush discharge.

If the electromotive force were carried still higher, the current would jump through the air from one conductor to the adjacent one; but in the case of wide separations, such as are usual, this would require an electromotive force greater than anything either contemplated or necessary. In the case of arcing, the line is short-circuited, and continued arcing would mean a cessation of power supply.

Since the appearance of the corona and the brush discharge represent power losses which may be of considerable magnitude, it is desirable that the line be so proportioned and operated at such potential as to avoid them, and this is particularly necessary in the case of transmission systems which supply only a small amount of power, because the energy loss due to the corona effect is independent of the energy transmitted over the line, being fixed by the voltage and not by the energy. Therefore, while the losses might represent a small percentage of a large amount of power, they would be a large percentage of a small amount.

A proper investigation of this subject requires first a consideration of electrostatic phenomena in general. In a paper[1] by Lamar Lyndon, who has collated existing data on the subject by authorities, Mershon, Ryan and Steinmetz, the following conclusions are enumerated:

[1] The Corona Effect and its Influence on the Design of High Tension Transmission Lines. Philadelphia Section, *Am. Inst. E. E.*, Nov. 9, 1908.

1. The critical voltage is dependent on the diameter of the conductors, their distance apart and atmospheric conditions, increasing with both diameter and separation of the conductors.

2. After the critical voltage is reached the losses increase very rapidly with increase in voltage.

3. The critical voltage and the magnitude of the losses after it is obtained are affected by atmospheric conditions, and therefore varies with the locality and season of the year.

4. In the same section of country a voltage which is normally below the critical point may be at times above the critical voltage with changes in weather conditions.

5. Smoke, fog, moisture or floating particles increase the losses, while the effect of rain is appreciable.

6. With increase in separation of conductors the regulation and power factor are diminished.

7. A separation of ten feet between wires is as great as is commercial or desirable.

8. The same law applies to cables as to solid wires, the diameter of the cable being effective diameter of the conductor.

9. The losses appear to be independent of the material of which the conductors are composed.

10. The losses and the critical voltage appear to decrease slightly with the frequency.

11. A transmission line should be designed for the atmospheric conditions that may obtain in the locality through which it passes.

12. All corona formation and losses depend on the maximum value of the voltage waves. Therefore the ratio of the maximum to the mean value should be definitely known to properly design a transmission system.

13. The limiting voltage (effective) which may be applied to a circuit of No. 0 wires, seven feet apart, with a maximum vapor product of 0.4, and keep down the line loss due to the corona within three kilowatts per mile, is approximately 110,000 volts.

14. High-tension transmission systems working under potentials exceeding 150,000 volts must have the wires covered with some insulating material having a greater dielectric strength than air, or use conductors of abnormally great diameter.

The paper shows that under usual atmospheric conditions, which prevail throughout the United States, the following formula is applicable:

$$E = 148{,}000 \times (r \times .07) \times \log_{10} \frac{D}{r}, \text{ in which}$$

E = effective voltage at which the corona will form and loss begin.

r = radius of conductors in inches.

D = distance apart of conductors in inches.

Obviously the voltage applied should be less than that at which the corona is formed.

From the formula, it is evident that after a separation of 100 times the radius of the conductors has been reached, any further separation is practically negligible in its effect, and with very high potentials the only remedy against corona losses is the increase in the diameter of the wire. A practical example shows, that for a potential of 250,000 volts and a conductor separation of 90 inches, the diameter of the conductors must be 1.5 inches.

Such a conductor would contain far too much metal to be easily supported in the air or for the necessary conductivity. Therefore it is believed, that a large jute or hemp core overlaid with a thin sheath of stranded copper or aluminum is the proper conductor to use on high-tension lines; the metal sheath being of such a thickness as will give the requisite cross section to transmit the energy of the system.

POLE AND TOWER CONSTRUCTION.

For carrying the conductors of a transmission system, the following pole and tower construction is used:

1. Wooden poles.
2. Concreted wooden poles.
3. Reinforced concrete poles and towers.
4. Steel pipe poles and towers.
5. Structural steel towers.

Of this wide variation wooden pole and structural steel towers are chiefly used; however, the different types will be successively treated.

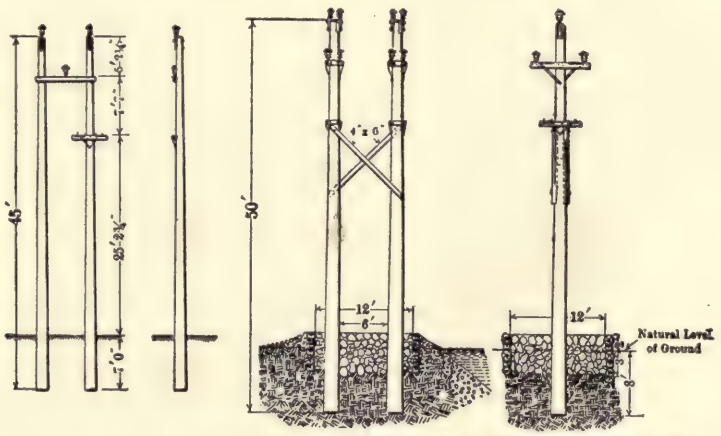


FIG. 1.—Types of poles used at the 50,000 V. Line of Taylor's Falls, Minneapolis Power Transmission.

WOODEN AND CONCRETE POLES.

Wooden Poles. Where the transmission line runs through a section or in the vicinity of a forest district, where poles may be cut, the wooden pole is more apt to be chosen because of its cheapness, little or no transportation, and ease of erection. Another advantage is, that they offer better protection for the community, because they are insulators. The disadvantages in the use of wooden poles are, that they

decay very rapidly; more insulators are required owing to the short spacing; they are readily destroyed by storms, lightning and fire.

Taking the given disadvantages into consideration, which in many instances outstrip the advantages, for instance the first cost, one will find to-day in thickly wooded sections, steel towers carrying the transmission line conductors.

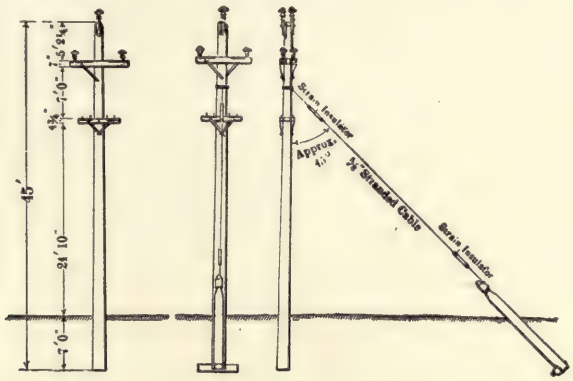


FIG. 2.—Typical Three Phase Circuit Poles.

The ordinary type of line construction is a single pole with cross arms as seen in Figs. 1 and 2. Other types are the "A" frame and "H" frame, both of which require two poles. The latter types must be properly braced and securely bolted, to prevent any deformation due to excessive stresses. These structures are, according to A. C. Wade[1] who made exhaustive tests on the various types of wooden poles and frames, 3 to 4.5 times as strong as a single pole.

Strength of Wooden Poles. For calculating the stresses in wooden poles the following formula may be used.

$$M = \frac{\pi R^3 S}{4 H}$$

M = bending moment.
R = radius of section at ground level.
S = strength of wood per square inch.
H = height above ground of force applied.

This formula applies only to a pole of uniform cross section. In the usual case, the pole is tapered and will break about half-way between the ground and cross arm.

Kind of Wood. The kind of wood depends upon the locality through which the line runs, the cost and factor of safety desired. In western transmission lines, spruce and fir are much used, while in California, redwood is prevalent. Cedar and chestnut are also used; the former is expensive and has great durability. Pine is the most extensively used in pole line construction, owing to its cheapness, but has the disadvantage of a short life and inferior strength.

[1] The Use of Wooden Poles for Overhead Power Transmission, by A. C. Wade. *Inst. of Elec. Engineers of Great Britain*, May 2, 1907.

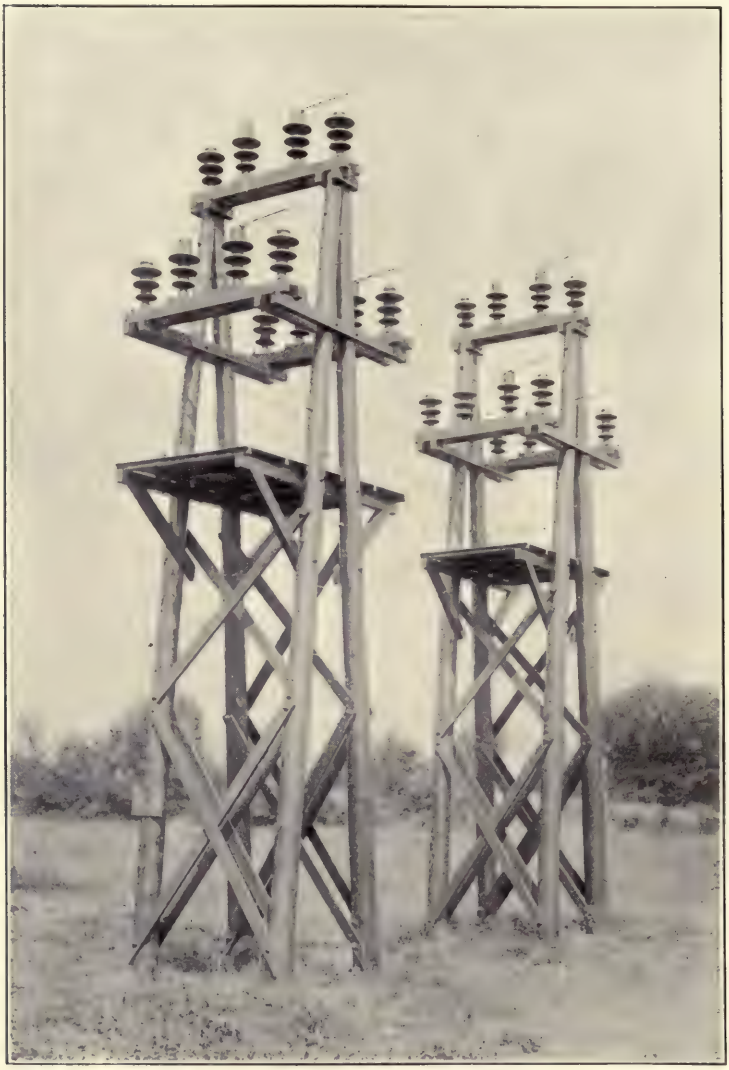


FIG. 2A.—Wooden Towers of the "A" Frame Type, with Disconnecting Switches.

Poles come in lengths varying from 30 to 60 feet; the butt diameters vary from 10 to 12 inches, and the top 7 to 9 inches. They are set with one-sixth to one-seventh of their length in the ground, and sometimes as high as one-eighth.

Cross Arms. The cross arms are made of first-class wood, such as chestnut, white oak, cedar, redwood, red or yellow pine. Arms 8 feet long are 4 by 5 inches in cross section, 3-foot arms about 3 by 4 inches. For long-span lines, the cross arms are sometimes made 6 by 6 inches. The cross arm must be properly braced to stand stresses applied on same. They are fastened to the pole by means of lag screws or bolts usually $\frac{5}{8}$ to $\frac{3}{4}$ inch in diameter. As a protection against splitting, the cross arms are through bolted on both sides of the pin. Experience has proven that certain cross arms split at a stress of 1200 pounds, while when through bolts were used, the cross arm failed to yield at 2000 pounds. For long stretches and on corners, the cross arms must be doubled, to stand the stresses. For medium spans where single cross arms are used, they must face the same direction on alternate poles, while the intermediate cross arms must face the opposite direction.

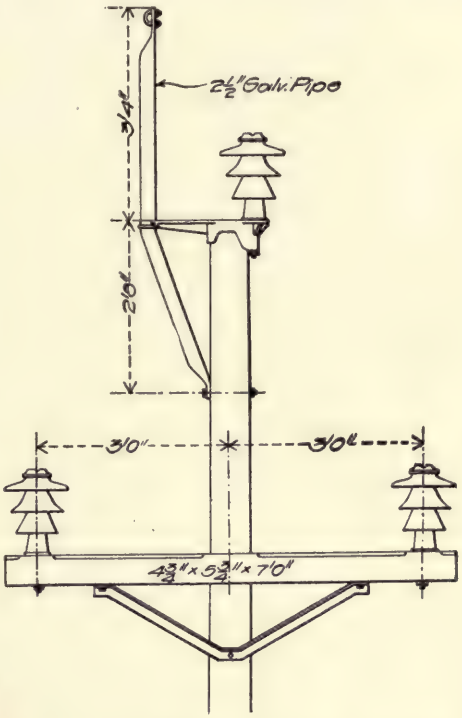


FIG. 3.—Arrangement of Cross Arm and Guard Wire. 40,000 V. Line.

Life of Wooden Poles. The life of a pole depends on the nature of the wood, chemical treatment, and climatic conditions, also character of soil. Redwood and cedar poles under favorable conditions may last 20 years, while the life of chestnut is about 15 years, and that of pine and white cedar, 10 years. When chemical treatment is applied, the life, of course, will be materially increased. Where poles are set in marshy ground, or ground which is alternately wet and dry, the life of the pole is correspondingly decreased.

Preservation of Wooden Poles. To lengthen the life of a wooden pole it must be properly preserved; it must be treated with some chemical compound. The simplest and least expensive way is to paint the top and butt, at least two feet above the ground level, with tar or creosote. More thorough methods of treating poles are done by special concerns, who treat the entire pole. The treatments are more or less identical, that is, the poles are placed *en masse* in inclosed cylinders and subjected to intense heat (usually steam), varying from 200 to 250° F.; then they are shifted to vacuum cylinders to remove the sap, after which they receive chemical treatment in a cylinder under pressure. The cross arms should be subjected to the same treatment. All cutting and trimming of poles must be done before they are sub-

jected to chemical treatment. Where drilling or cutting has to be done in the field, after treatment, these places must again be treated with chemicals, which are usually tar or creosote. The top of the pole must be beveled or a cast iron cap provided.

Pole Line Construction. To secure correct alignment, the location of the poles must be made with the aid of a transit, and the pole itself must be lined up with a plumb bob. The poles must be correctly distributed according to length. The cross arms may be mounted before the pole is set, and frequently the insulators are mounted at the same time. Poles up to 40 feet in length are usually erected by about 6 men with pikes, while poles above this, are preferably erected by means of a portable derrick and a team of horses, otherwise the services of 10 to 12 men are required. The poles are set either in concrete blocks or directly in the ground; in the latter case, they are frequently provided with a cross member to resist uplift. Where poles have to be set in marshy or swampy ground, it is frequently impossible to set them without very heavy footbracing, consisting of bracing with a semi-crib construction filled with ballast.

Guys. Where the line is dead-ended, and on sharp turns, poles are guyed where permissible. This practice is not to be recommended with steel towers, because, as the expenditure is made for a structural steel tower, the structure should be made stable enough to resist any strain or stress applied to same; otherwise wooden poles may be erected.

The methods commonly employed in guying are to bury a "dead man" in the ground or use some of the patent guy anchors now on the market. The "dead man" is a pole of short length buried in the ground some distance from the pole, and so placed that it lies normal to the direction of the guy wire fastened to it. The patent anchors are so made that little or no excavation is necessary to bury them. Other advantages of patent anchors are the ease of transportation, erection and removing same; several anchors can be readily applied to one guy.

Concreted Wooden Poles. The concreted wooden pole has not been used to any great extent. It has only been used, to the writer's knowledge, in Switzerland. It consists of an ordinary pole covered with a layer about one inch thick of concrete mortar. As this coating covers the entire pole, its life is made practically indefinite and the strength of the poles is materially increased, and so fewer poles and insulators are needed. The concrete block setting frequently required is eliminated.

Reinforced Concrete Poles. The ordinary reinforced concrete pole is of similar construction as most types of concrete piles. They are made solid or hollow, in cross, square or circular cross sections, and are reinforced by a number of iron or steel rods according to the strength of pole desired. As these poles may be made for any practical strength and length, it is a very convenient type of pole, particularly as they are readily made in the field.

A type of reinforced concrete pole, developed and used to some extent in Germany and recently introduced from Switzerland into England,[1] are hollow and tapering, in lengths up to about 40 feet. The machine is capable of making poles of any size and lengths within the limits of 40 feet long and 2 feet in diameter.

[1] *Electrician*, London, July 31, 1908.

In the process of manufacture, a long sheet iron core is mounted on two trestles, running on rails, so as to be capable of rotational and longitudinal movements. Upon this core, small longitudinal steel rods are fixed. The core is drawn through the machine, which is stationary.

Concrete made of clean screened grit and Portland cement is mixed dry in a mechanical mixer and discharged through a chute into a hopper or drum in which rotating paddle wheels regularly discharge the concrete upon a bandage of coarse webbing laid on a conveyor belt, that takes one lap around the core. This continuous traveling conveyor belt is stretched so that the concrete is wrapped about the core under great pressure. As the core issues beyond the conveyor belt, wire is fed spirally around it so as to press into the concrete wrapping, and small rollers then apply great pressure by working on the webbing, the slack of which, caused by the reduction in diameter resulting from this pressure, is taken up by another device.

The core as it issues from the machine is wrapped about spirally with a bandage of cloth. The machine pulls the trestles forward with the suspended core as the concrete is wrapped on, and when the core has passed completely through the machine it is lifted by an overhead crane and laid to one side to harden. It is kept constantly damp so as to secure the maximum hardness. In about twelve hours the interior sheet metal core is reduced in diameter by means of a screw attachment inside and withdrawn. After hardening six days the bandage of webbing is removed, and the whole is then complete for setting.

The poles are estimated to have a life of fifty years, and during that time will cost nothing for maintenance. On this basis the total cost of a pole at the end of fifty years is estimated to be $20.00 for the concrete pole, $50.00 for an iron pole and $53.00 for a wooden pole, all including maintenance, repairs and renewals. This is for a 29-foot pole. For a 36-foot pole for transmission service and for the same period, the corresponding figures are: for the concrete pole, $26.00; for the iron pole, $60.00; and for the wooden pole, $68.50. Any desired amount of ornamentation may be given to the poles. Some tests on a pole of this type, 32 feet 9 inches long, showed a deflection of $2\frac{3}{4}$ inches with a tensile strain of 15,000 pounds.

Tests on a Siegwart, 10-meter pole (39.3 feet) show the following results: with a pull of 880 pounds, the deflection was 1.1 inch, which increased to 3.5 inches with a pull of 1540 pounds; the permanent deflection being 2.5 inches, owing to the fact that the strain was slowly released. In another test, with a pull of 1540 pounds, a deflection of 2.75 inches was produced; when suddenly released, the top of the pole assumed its original position. A third test, with the application of a pull of 2200 pounds and 6.1 inches deflection, showed a permanent set of 4.72 inches with a gradual release of the pull. In all of these tests no signs of fracture or cracks appeared.

Steel Pipe Towers. The simplest form of a steel pipe pole is that of a single pipe with cross arms. For more rigid and higher constructions, three-legged poles have been constructed. Owing to the length, each leg is made in sections and coupled by nipples, the legs being cross-braced by angle irons and rods. Such towers have been constructed for the Ontario Power Company, but this type is now obsolete; it has been superseded by structural steel towers, which are more economical.

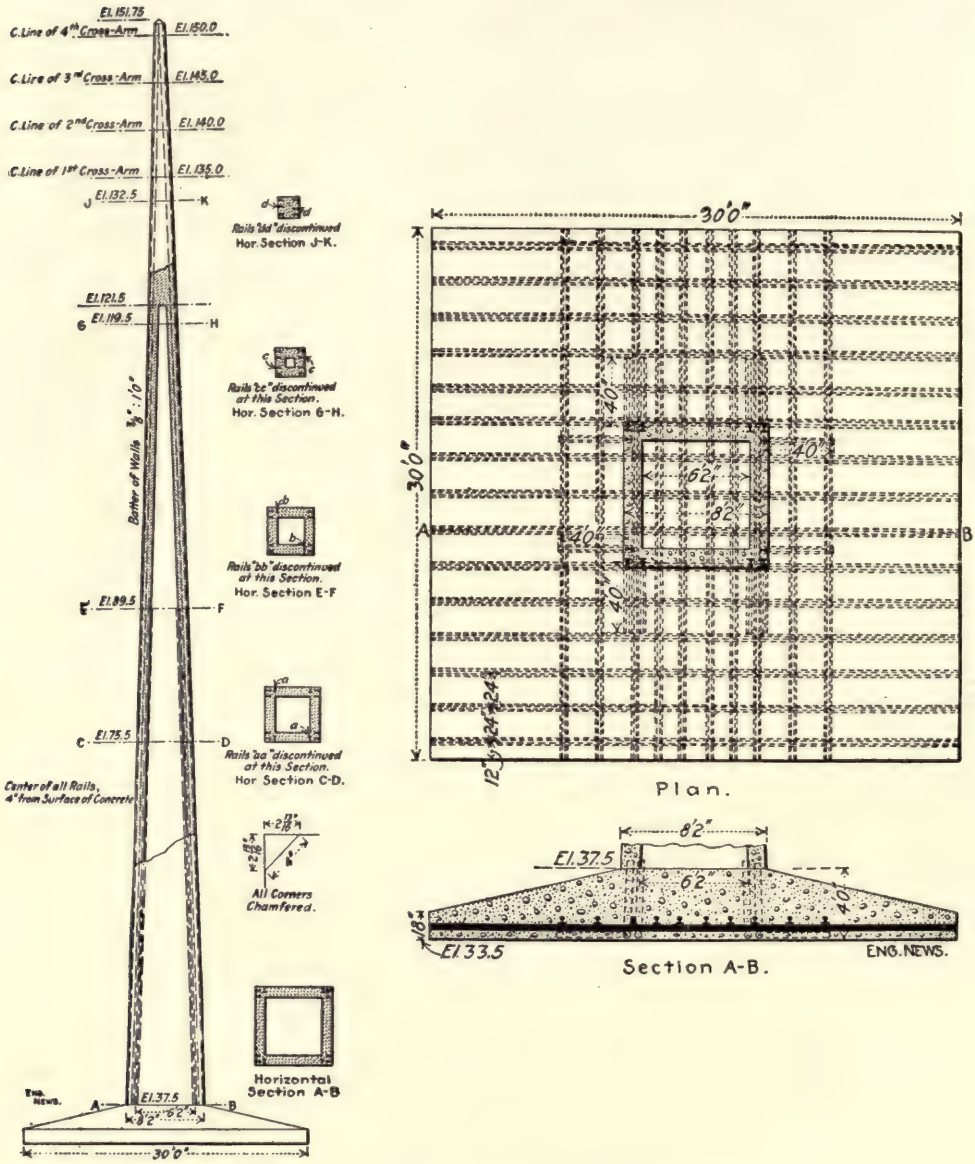


FIG. 1.—Reinforced Concrete Tower and Foundation.

REINFORCED CONCRETE TOWERS.

Where special long and high spans are required, high towers are necessary. A few of such towers have recently been built of reinforced concrete; for instance those at Brownsville, Penn.,[1] erected by the West Pennsylvania Railway Company, for carrying a transmission line across the Monongahela River. The main tower rises 150 feet above its foundation; the second tower is but 55 feet high and located

[1] Reinforced Concrete Towers for High Potential Transmission Lines, by F. W. Scheidenhelm. *Engineering News*, May 2, 1907.

230 feet behind the first, and acts as an anchorage, taking the direct strain of the main span which is 1014 feet. They are reinforced as follows:

For reinforcement old T-rails were used. All of the rails forming the vertical reinforcement were of 60 pounds section. The safe unit stresses were cut down to allow for the wear which many of the rails showed. Incidentally, the use of rails solved the problem of the end-to-end connection in the case of the vertical reinforcement, for the ordinary spliced-plate joint thus became possible. On the other hand, the large cross section of each rail was a disadvantage. In certain sections of the towers, for instance, it was necessary, under the circumstances, to insert the full cross section of a rail, even though only a fraction of it was required by the stress to be carried. The base section of the main tower contains twelve 60-pound rails, three being placed at each corner, while the base section of the anchorage tower contains ten rails in the tension side and two in compression. Thus the main tower base contains 1.73 per cent of steel, and the anchorage tower base 1.25 per cent.

In addition to the vertical reinforcement of rails, a spiral winding of three-eighths cable was used. Two spirals were wound, 1 foot apart, thus giving a 2-foot pitch. Tie wires secured the spiral winding to the vertical reinforcement, the concrete being 1:2.5:5 for the footings and 1:2.5:4 for the tower.

STEEL TOWERS.

With the introduction of high-tension transmission, wooden poles are fast being substituted by structural steel towers. The majority of transmission lines now in use employ this type of tower. They are made up of angles, channels and lattice construction, and in two, three and four-legged type.

All towers for carrying transmission lines have to be calculated to withstand the following general conditions:

They must be self-supporting, strong enough to carry the line conductors and to resist the wind pressure on the conductors and tower itself. To this must be added the load due to sleet, and the effects of temperature changes, as well as a factor of safety to guard against accident, such as the breaking of one or more conductors.

Wind Pressure on Structures. The records of the United States Weather Bureau are available as an aid in estimating the maximum velocity to be expected in a given locality. These published velocities are not accurate, but must be corrected by a correction table, which may be obtained from the Weather Bureau and is as follows:

TABLE I. — CORRECTED WIND VELOCITIES.

Indicated velocity.	Actual velocity.	Indicated velocity.	Actual velocity.
10	9.6	60	48
20	17.8	70	55.2
30	25.7	80	62.2
40	33.3	90	69.2
50	40.8	100	76.2

The relation between wind velocity and the pressure produced by the wind on a plane surface normal to the direction of the wind is given by Scholes[1] in the following:

$$M = KV^2,$$

M = pressure in pounds per square foot.
V = wind velocity in miles per hour.
K = constant.

Experiments in general, indicate that this form of equation is correct, but differ as to the proper value of K. According to tests by the Weather Bureau, $K = 0.004$, which is probably the most reliable figure.

Experiments indicate in general, higher pressures are to be expected at the top of a tower than near the ground, but little is known as to how the pressure is distributed. There is considerable doubt as to what should properly be considered the exposed area of a structure; it is certain, however, that both faces are not, in general, subject to the same pressure. It is usually considered that a reduction factor of 0.5 should be used in figuring the wind pressure per square foot, of projected area of cylindrical surfaces. The wide use which has been given this factor is its principal recommendation.

It appears, therefore, that it would be good practice in transmission-line construction to specify that the poles or towers should, in addition to their other properties, have strength to resist loads on their members due to a wind pressure of 40 pounds per square foot, with a factor of safety from 1.5 to 2, based on actual test. Such a structure would be suitable for locations where the winds are high; in other locations these figures would be reduced by judgment, aided by a consultation of the weather reports and other such data.

Wind Pressure on Conductors. It is not necessary to allow as high a pressure on the conductors of long spans as on the tower itself; however, there are little definite data available for such calculation, but a value of 30 pounds per square foot is usually chosen for localities where the wind velocities are high. In order to keep the stresses of a conductor within its elastic limit, a factor of safety of at least 2 should be chosen.

Sleet. Where the transmission line runs in temperate zones, the weight of sleet must be considered. (Specific Gravity of ice is 0.92, or 57.4 pounds per cubic foot.) Although sleet collects in the middle of the span with a greater thickness than near the towers, the usual practice is to allow 0.5 inch thickness, so that the diameter of the cable is increased one inch. As the sleet is apt to remain several days, during which time high wind storms may occur, it is necessary, therefore, that when calculating the wind pressure, the increased diameter must be considered.

Foundations. The foundations of towers are made of concrete, or cross members are buried in the ground under heavy ballast. The former is the most common method. They must be heavy enough, or so designed to resist the uplift, equal to the weight of the foundation plus the weight of earth taken at the angle of repose.

[1] Fundamental Considerations Governing the Design of Transmission Line Structures, by D. R. Scholes. *Am. Inst. of E. E.*, Atlantic City, N. J., June 30, 1908.

A.E.&M. UNIV. OF CA

In designing towers, tests of the soil should be made to determine its holding power and carrying capacity. Many of the foundations for recent installations are of reinforced concrete. They have the form of an inverted T. The horizontal cross arm gives additional anchorage to resist uplift. Another advantage of the reinforced concrete foundations is, as they are comparatively light they may be made on one or more sections of the line and transported to place.

Portability. It is but natural that most transmission lines run through sections of country where transportation facilities are seriously handicapped. Besides this, the towers for modern transmission lines are of such large size that it is difficult to ship them by rail or water, therefore it is necessary to design them so that they can be transported in pieces, known as "knocked down." The members of the towers can be readily transported on the backs of burros or mules.

Two-Legged Towers. As stated, towers are designed with two, three or four legs. The two-leg type is made of two channels or I-beams either in H or A form, and cross-braced. With this type of tower carrying three conductors, the possibility is, that if two or all conductors break, the adjacent towers may be deflected, and likewise the next towers may be somewhat affected. In order to overcome the possibility of several towers being affected, every fourth or fifth tower may be rigidly guyed.

This type of tower for three conductors is sufficiently strong in the transverse direction, and for short spans in general; however, when long spans come into consideration, they are weak in the longitudinal direction. When, however, the tower carries six or more conductors, as, for instance, in the later described Italian tower at Tretzo, where twelve conductors are carried on a tower, the breakage of a few conductors amounts to but a comparatively small per cent of the total, and the tower is little or none affected. As stated, this tower has been erected to carry spans up to 600 feet.

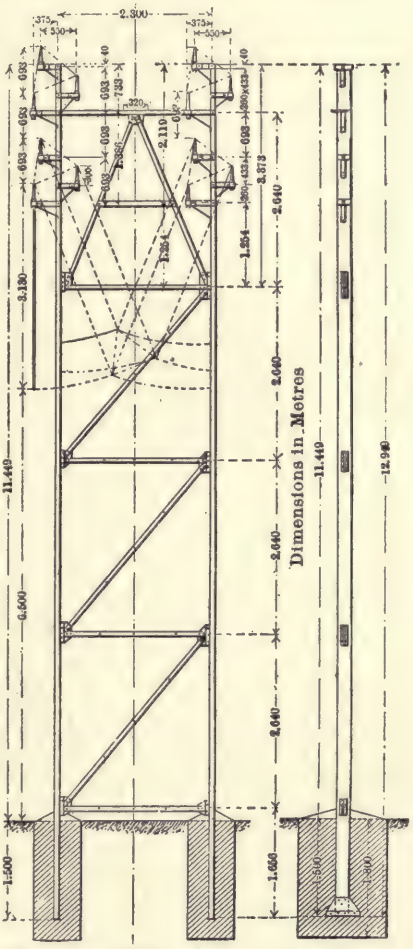


FIG. 1. — Two-Legged 37-Foot Transmission Tower, Used in Switzerland and Italy.

The standard towers of the 75-mile, 52,000-volt Gaucin-Seville, Spain, transmission system, are made in H-frame of two channels with diagonal bracing of flat bars, and accommodate two 3-phase circuits.

Another two-legged tower transmission system is that for Moosburg to Munich, Germany, a distance of 32 miles. These towers are of the A-frame type, and carry

a single 3-phase circuit and two telephone lines. One conductor is carried on the peak of the frame, and the other two on a common cross arm.

Before the contracts for the transmission structures were let, tests were conducted on (1) wooden A-frame structure; (2) steel tube poles; (3) Mannsmann tube poles; (4) latticed tower of angle iron; (5) I-beam A-frame.

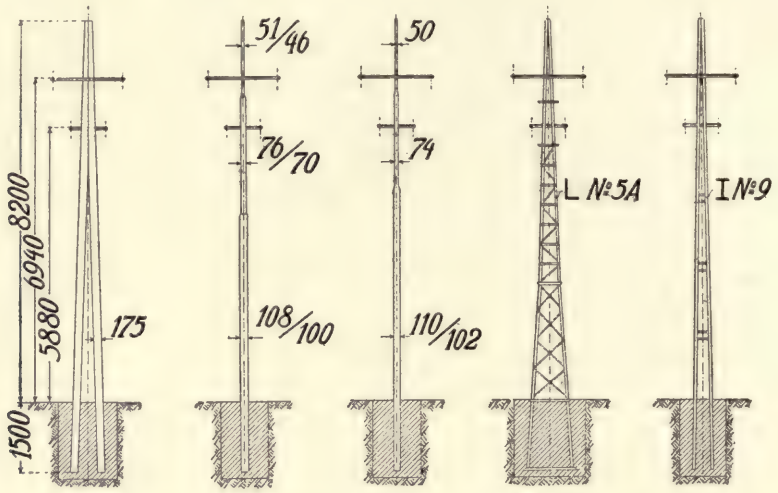


FIG. 2.—Types of Poles and Towers tested before Contract was let for 50,000-volt Transmission System, Moosburg, Munich, Germany.

The following table gives a comparison of the tests on the above structures, together with the prices in marks. The structures are tabulated successively as above numbered, and are expressed in the metric system and serve for ready comparison.

	1	2	3	4	5
Res.-Mom. in line direction in cm^3.....	990	32.2	33.9	353	52
Res.-Mom. in transverse direction in cm^3.....	5440	32.2	33.9	353	52
Safe load in kilograms.....	100	1800	2200	870	1800
Cost in marks including two cross arms.....	35.20	40.35	45.20	80.70	40.00

It will be noticed that the wooden structure was not favorable, especially as the line passes through marshes, and the life of a wooden structure is short. The I-beam structure outstripped the others regarding safe load and price, which is the reason why this structure was adopted.

The standard tower is 23 feet to the lower insulator, and is embedded 5 feet deep in a concrete block, and carries three solid copper conductors; the standard spacing is 165 feet.

The towers are made up of two I-beams braced at three points; as the cross sections of the conductors vary from 70 to 16 square millimeters, the size of the I-beams varies from 5.5 to 3.5 inches correspondingly. None of them are provided with

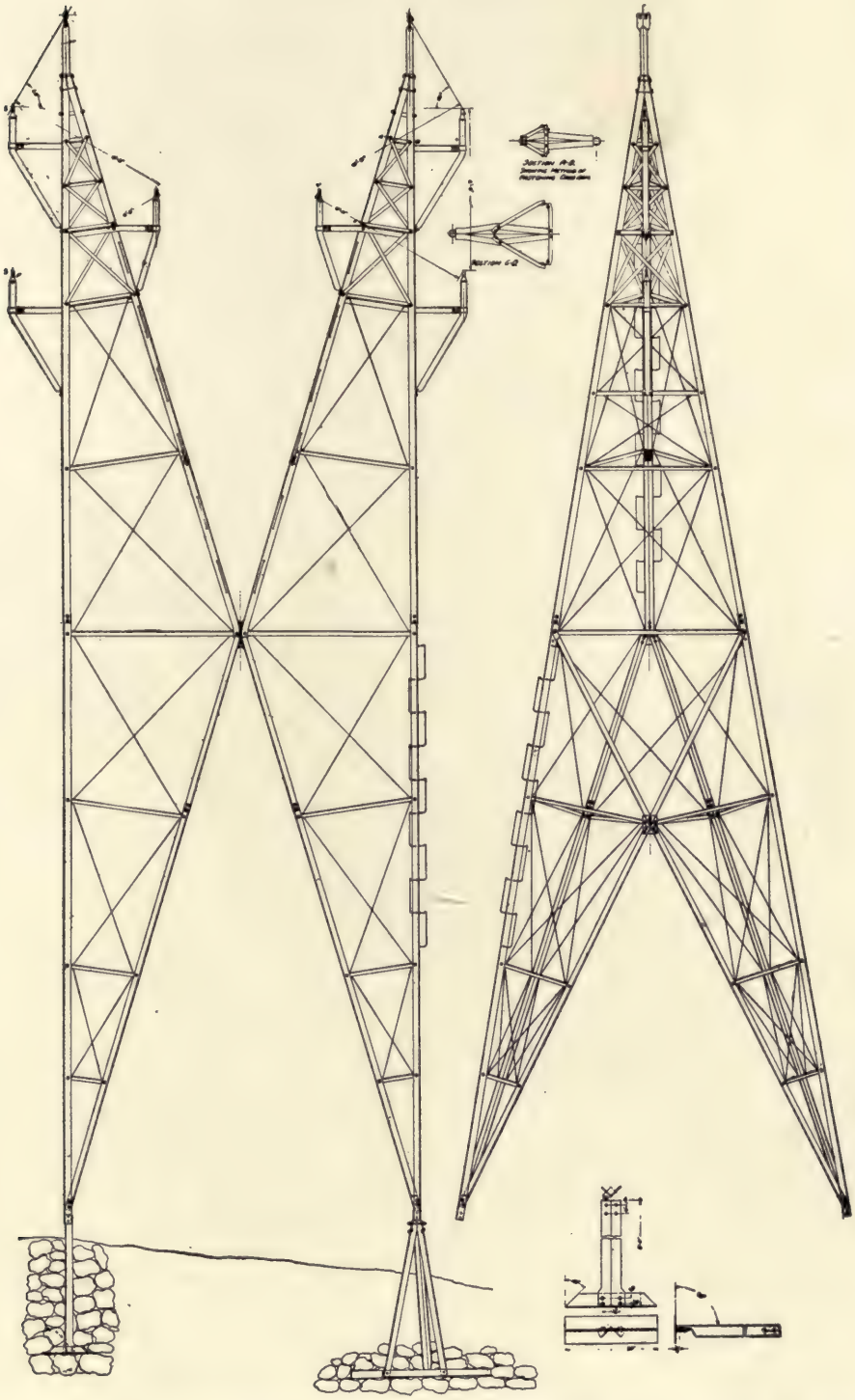


FIG. 3.—Aermotor Four-Legged Twin Tower with Ground Wire Pin as used by the Southern Power Co., Charlotte, N. C. This Type is a Combination of Two Three-Legged Towers.

guy wires. There is a total of 2260 towers, which were erected by two gangs, each consisting of 40 men capable of erecting, on the average, 20 towers per day. As nearly the whole course follows the river Isar, all of the material was conveniently transported on boats.

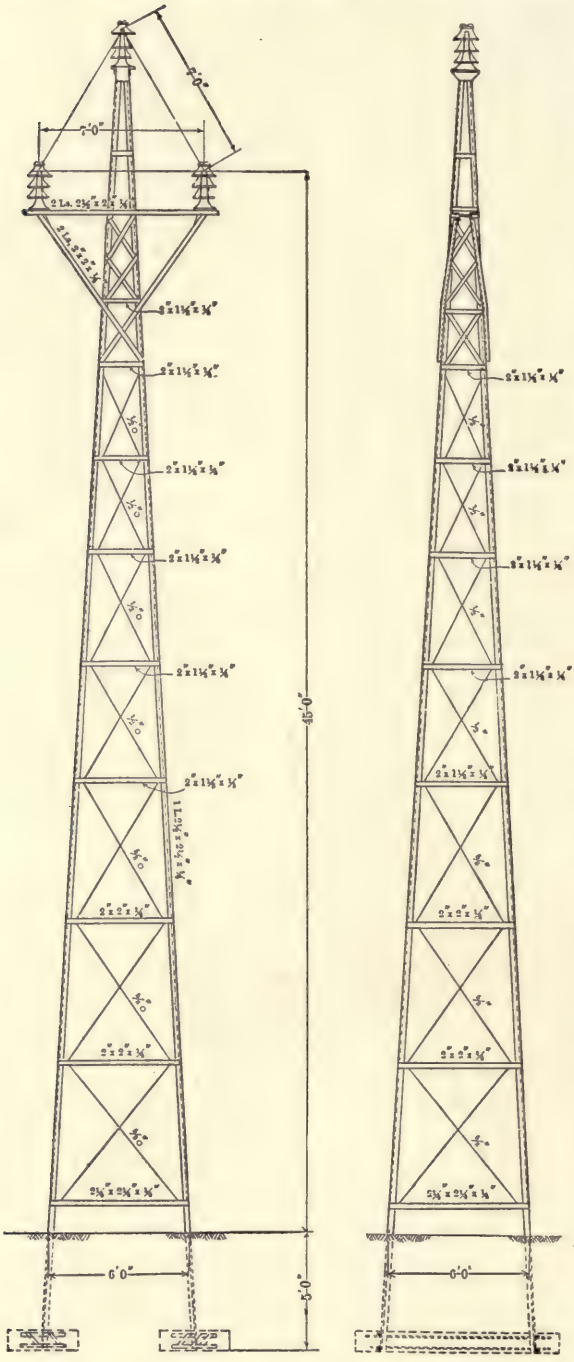


FIG. 4.—Detail of 45-Foot Angle Iron Tower at Syracuse, N. Y.

Three-Legged Towers. This type of tower is used for small conductors carrying not more than 33,000 volts. They are economical in design, and made up of light angle irons. Owing to the triangular section, the stresses due to the conductors only, are distributed unequally on the three legs; the tower itself cannot be surpassed by any other type.

A tower possessing some of the features of a three-leg type, yet having a rectangular plan on its base, is the combination of two 3-pole towers, and is known as the "twin tower." These towers are interconnected at a common point, as seen in Fig. 3.

Four-Legged Towers. The towers in which the stresses, transverse as well as longitudinal, are equally distributed, are of the four-leg type. They are made up of angle iron and frequently cross-braced with rods instead of angle iron, and in almost all cases are designed to withstand the stresses set up when two-thirds of the conductors break; for further security, they are double guyed at intervals, as has been done on the Niagara, Lockport and Ontario Company's transmission line; this precaution, however, is only necessary when all the cables should break at once. Such occurrences rarely happen.

Tretzo Tower. The first structural steel towers are found in Switzerland and Italy, and some of the recent transmission lines still employ a similar type of tower as seen in Fig. 1. It consists of 2 channels with angle cross-bracing. This type of tower has been installed at Tretzo, in the northern part of Italy; it is 37 feet high



FIG. 5.—Niagara Crossing. Water Edge Tower, American Side.

above the ground, while 5 feet is embedded into a concrete block. The average spacing of these towers is 350 feet, while on this particular line, the long spans are 600 feet.

Syracuse Tower. Fig. 4 shows a section of the 60,000-volt transmission line tower of the Syracuse Rapid Transit Company, New York,[1] along the Erie Canal. The

[1] The 60,000-Volt Substation and Transmission Line of the Syracuse Rapid Transit Company. *Street Railway Journal*, July 14, 1906.

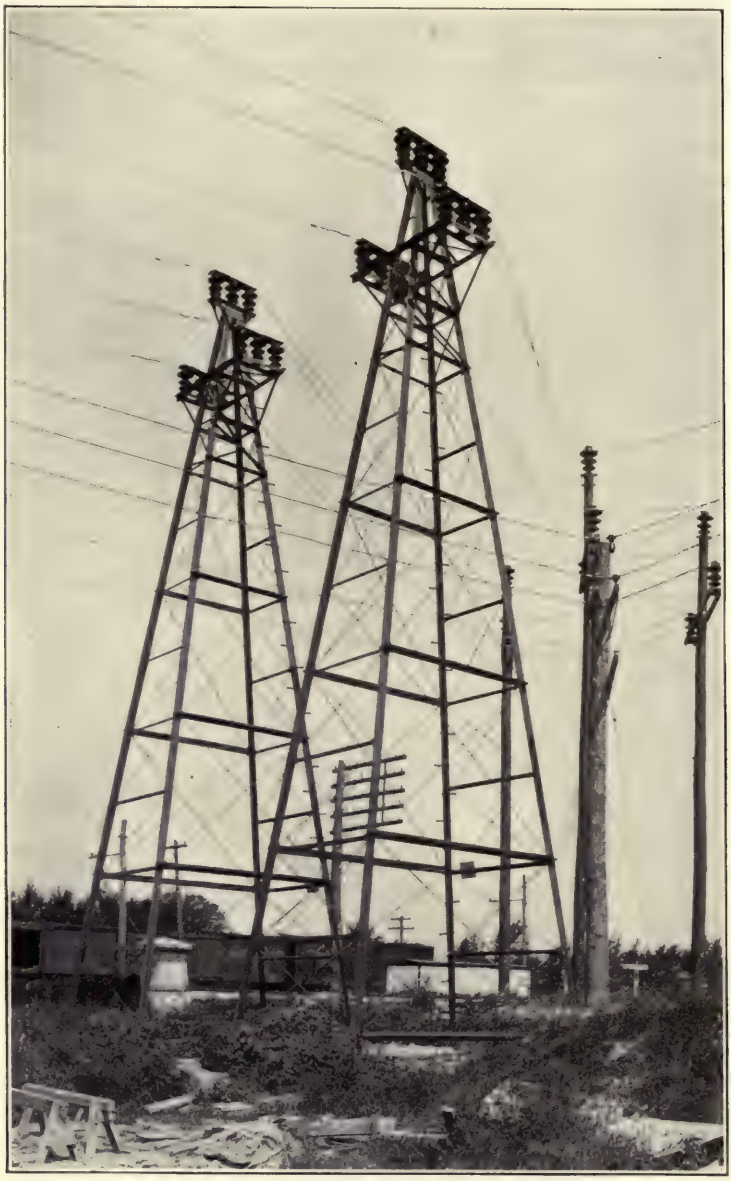


FIG. 6.—Dead End Towers at the Rochester Substation. Niagara, Lockport and Ontario Power Co. Designed to Resist a Total Pull of 11,000 lbs. per Cable. Archbold-Brady Co.

route of the line is within the limits of the city of Syracuse; and the towers, which were built by the Archbold-Brady Company, Syracuse, are from 45 to 63 feet high, measured from the ground to the top of the bottom insulator, and are spaced on the average, 240 feet; the longest span is 407 feet. The conductors consist of seven-strand seven-sixteenths-inch plow steel cable.

In designing the line, the assumed wind load was taken as 1.25 pounds per lineal foot of cable. This estimate was based on a wind pressure of 30 pounds per foot

on a flat surface, or 15 pounds on a round surface. The dead-end towers were designed also for endwise strains under maximum wind and sleet loads, and calculating these strains, a sag not exceeding one-twentieth of the span was allowed. The minimum sag allowed was 1 foot in 40 feet. The heights of towers were arranged to provide ample clearance over buildings and wires. The towers at the angles were designed to provide for side strains due to the tension in the cables based on the sags started, and also for the pressure of the wind on the cable and on the tower. Enough insulators were provided at the angle towers so that the cable does not make any angle of over 8½ degrees on any one insulator. Where possible, the cable was slacked off on spans adjacent to angles of over 3 degrees. The towers at angles and dead-ends are stiff structures designed to provide for the greatest assumed strains. In towers of greater height, the section of upright members in lower panels was increased. The cross-arms of all towers were designed to resist torsional strains due to the pull of the cable on the tops of insulators. The maximum pull allowable with assumed unit strains on a single cross-arm tower was 1000 pounds for each cable. The cross-arms of towers at dead-ends carry three insulators for each cable, and are designed to resist the maximum calculated pull due to the assumed conditions of load and sag. Bolted joints in the main members of towers were designed on the basis of 10,000 pounds shearing per square inch and 20,000 pounds bearing per square inch.

The following are the chief features of the towers: The towers are of the four-leg type and are built up of angles. The members of the upper section are laced and riveted together, and the horizontal members throughout are riveted to the upright members. The diagonal rod members are adjustable by right and left threads and clevices at the ends. The cross-arms are specially designed and braced to resist possible torsion should one or all of the cables break. All metal is one-fourth inch thick or more. Towers 57 feet high and over are supported on concrete piers. Each leg of the tower is anchored by two 1-inch bolts running to the footings. The footing under each pier is 5 feet by 3 feet by 12 inches thick, reinforced to resist uplift.

Oneida Tower. Towers similar to these have been installed by the Oneida Railroad Company, for its electrification work. The standard height is 39 feet, while special towers run up as high as 69 feet from the ground to the top of the bottom insulator. The average span is 480 feet long. For the following specifications of this transmission line, the writer is indebted to the designers and constructors, Archbold-Brady Company, Syracuse, N.Y.

SPECIFICATIONS

FOR HIGH-TENSION LINE CONSTRUCTION FOR THE ONEIDA RAILWAY COMPANY, BETWEEN CLARK'S MILLS AND MANLIUS CENTER, N. Y.

This specification is intended to cover the construction of a 60,000-volt transmission line along the north side of the West Shore right of way between the substations of the Oneida Railway Company at Clark's Mills and Manlius Center, N.Y.

The conductors will be of No. 0 stranded copper supported upon structural steel towers with concrete foundations.

Towers. — The towers will be of structural steel, as per blue prints herewith, and will be designed to sustain the assumed loads as follows:

The side pressure of the wind will be taken at $1\frac{1}{4}$ pounds per lineal foot of cable based on a wind pressure of 30 pounds per square foot on a flat surface or 15 pounds per foot on a round surface, acting upon a cable covered with a thickness of sleet equal to its own diameter.

The heights of towers will be arranged to provide a minimum clearance of 10 feet over buildings and such wires as may be crossed by this line.

Towers at angles will be designed to provide for side strains due to the tension of the cable itself and for the pressure of the wind on the cables and on the tower. Enough insulators will be provided at the angle towers so that the cable will not make an angle of over $7\frac{1}{2}$ degrees on any one insulator. The wind pressure on the tower itself will be assumed at 60 pounds per panel on each half of tower.

Unit Strains. — The section of members in the tower will be calculated for a unit strain of 24,000 pounds per square inch due to the combination of loads stated above. The strains in compression will be based on the formula,

$$24{,}000 - 96\frac{L}{R}.$$

Design. — The design of towers in general will be as per drawing of 45-foot tower herewith. In towers of greater heights, sections of upright members in lower panels will be increased. The cross-arms of all towers will be designed to resist torsional strains due to the pull of the cable on the tops of insulators. The maximum pull allowable on a single cross-arm tower will be 1000 pounds for each cable, the ties being designed to break at this tension. The cross-arms of towers at dead-ends will carry three insulators for each cable and will be designed to resist the maximum calculated pull due to the assumed conditions of load and sag. Bolted joints in the main members of towers will be designed on the basis of 10,000 pounds shearing per square inch and 20,000 pounds bearing per square inch.

Foundations. — Foundations of all towers will be as per drawing herewith. For towers below 57 feet high, the legs of tower will be extended into the ground to a concrete footing about 3 by 7 feet reinforced at top and bottom as per drawing. The metal below the surface of the ground will be protected by a 6-inch concrete sleeve run in sheet-metal form and extended slightly above the ground surface. In wet places this protection will be carried above the surface of the ground, and the portion of corner posts below the splice angle will be lengthened in proportion.

Foundations of towers 57 feet high and over will be concrete piers as per drawing. Each leg of the tower will be anchored by two one-inch bolts running to footings. The concrete will be proportioned one part cement, three parts sand and five parts broken stone, or may be one to six cement and clean sharp gravel. The footing under each pier will be 5 feet by 3 feet by 10 inches thick reinforced at top and bottom. Where the ground is firm, no forms will be used around footings. The concrete for piers will be placed in forms of planed lumber. All piers must be carefully leveled up with neat cement at the top, this cement to be put on before the forms are stripped. The foundation bolts will be set with wooden templates and to elevation shown on working drawings.

Steps. — Steps about 20-inch centers will be provided for each tower extending from first panel to cross-arm.

Construction. — The towers will be riveted in the shop as far as practicable. The field connections may be bolted. The bolts in the two lower panels will be upset.

Pins. — The pins will be of malleable iron 18 inches high above cross-arm and designed to withstand a strain of 2000 pounds in any direction applied to the insulator. They will be attached to the tower with four $\frac{5}{8}$-inch bolts.

Dead-End and Special Structures. — Where the line is dead-ended or where special structures are required at the sub-stations a separate agreement will be made, these structures not being included in this contract.

Handling and Stringing Cables. — The cable will be delivered to the contractor at convenient freight stations along the line. The contractor will string same upon the towers, using great care that the cable is not kinked or damaged during the operation. The cable will be strung in general with a

12-foot sag on 480-foot span at 32° F., which corresponds to a normal tension of 300 pounds in the cable. Allowance will be made for temperature so that the cable will have a sag of 12 feet at 32° F. Where the spans vary, the sag will be proportioned so that the normal tension in the cable will remain practically the same.

The cable will be tied in with wire furnished by the company, the form of tie to be agreed upon later, but these ties will have, as near as practicable, a breaking strength of 1000 pounds. On the double cross-arm equalizing saddles will be provided to insure equal strains being brought upon the insulators. At the dead-end towers, clamps will be arranged for holding the ends of the cable securely. Saddles will be designed to facilitate removing of a defective insulator.

CHARACTER OF WORK. — All work in shop and field must be carefully and accurately done, and the structures left complete and finished according to the best practice in this class of work.

PAINT. — All work to have one shop coat of red lead and oil and one coat in field of graphite paint of approved manufacture. All work to be done according to the directions of the Engineer of the Oneida Railway Company.

New York Central Tower. A steel tower of lattice construction for carrying a number of conductors on wooden cross-arms, as installed in connection with the New York Central and Hudson River Railroad, is seen in Fig. 7.[1] "The component parts of the tower consist of the following: Four L's 3 inches by 3 inches by five-sixteenths inch; lacing, one L 2¼ inches by 1½ inches by three-sixteenths inch (single); connecting L's 2½ inches by 2½ by one-fourth inch; cap plate of malleable iron; rivets three-fourths inch in diameter. The estimated quantities of material for one pole are: steel, 1340 pounds; concrete, 6.5 cubic yards; timber, 71 feet board measure.

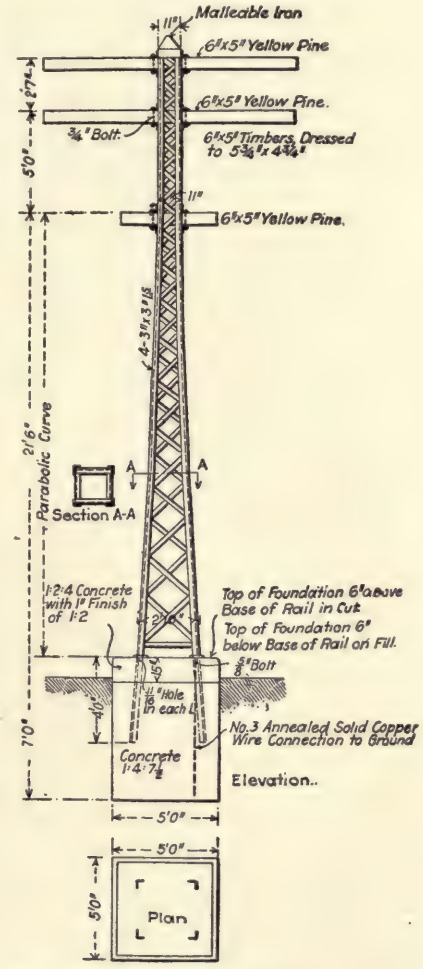


FIG. 7.—Standard Steel Tower of the New York Central Railroad.

The general conditions in installing the lines were as follows: Distance from the center to center of poles on tangents is 150 feet, sag 30 inches; distance on 1-degree curve is 141 feet, sag 27 inches; on 2-degree curve, 133 feet, sag 24 inches; on 3-degree curve, 125 feet, sag 21 inches; on 4-degree curve, 118 feet, sag 18½ inches; on 5-degree curve, 112 feet, sag 16½ inches; on 6-degree curve, 107 feet, sag 15 inches. The sag of wires for all spans is computed at 70° F. with no wind. Load on poles: Six-wire circuit No. 1, each 0.728 inch diameter, area 400,000 C.M., weight

[1] Two Forms of Transmission Towers in New York State. *Street Railway Journal*, July 14, 1906.

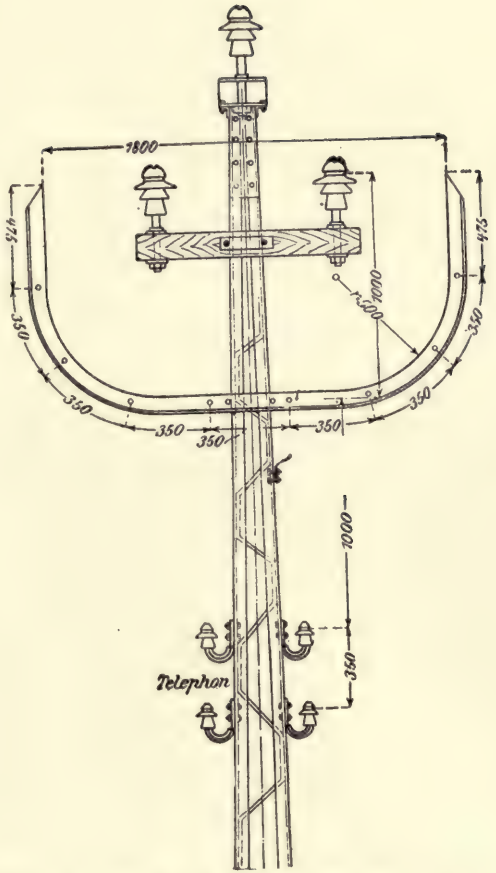


FIG. 8. — Type of 35,000-volt Tower with Brackets for Guard, Heimbach Plant, Germany.

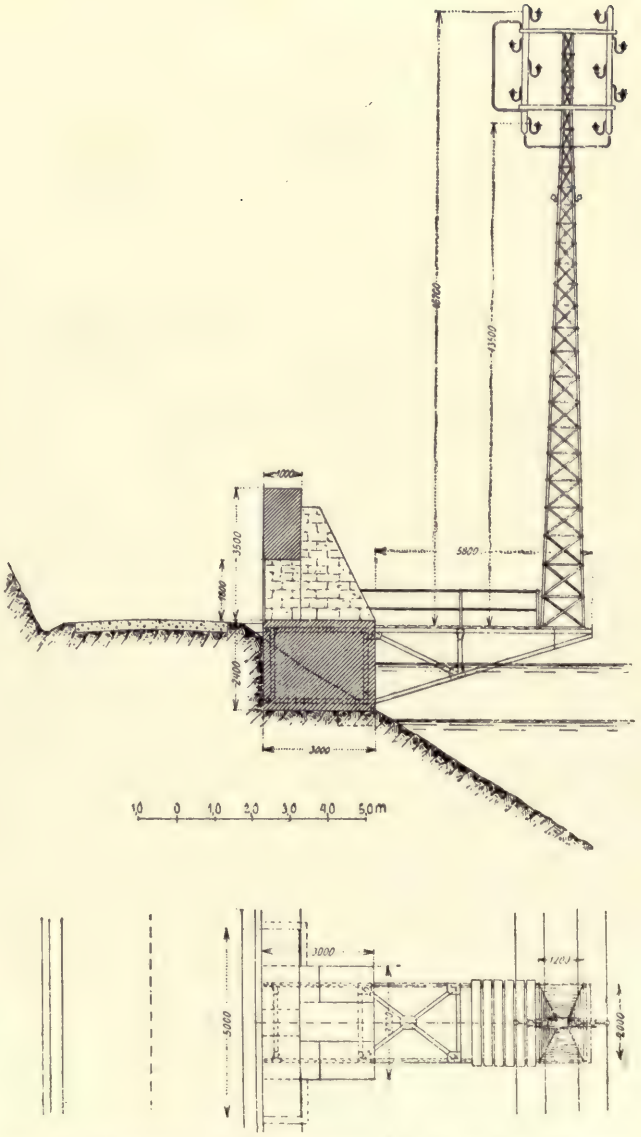


FIG. 9. — Cantilever Construction of 27,000-volt Transmission Tower, Obermatt-Lucerne, Switzerland.

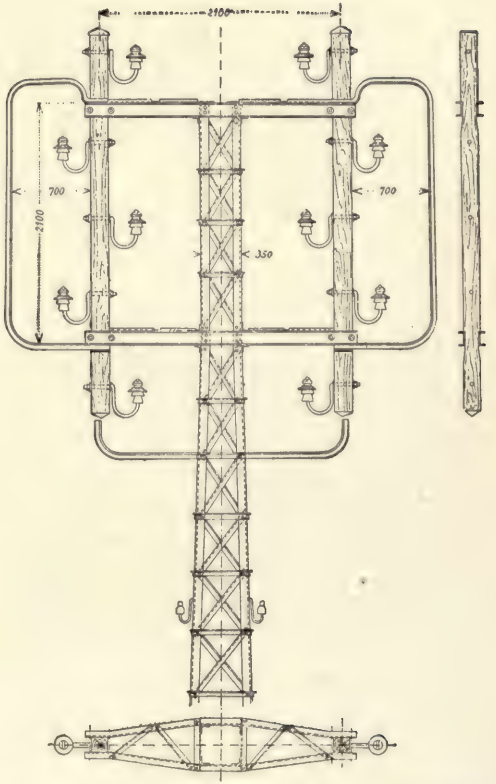


FIG. 10. — Detail of 27,000-volt Transmission Tower, Seen in Fig. 9.

A.E.&M
UNIV. OF C

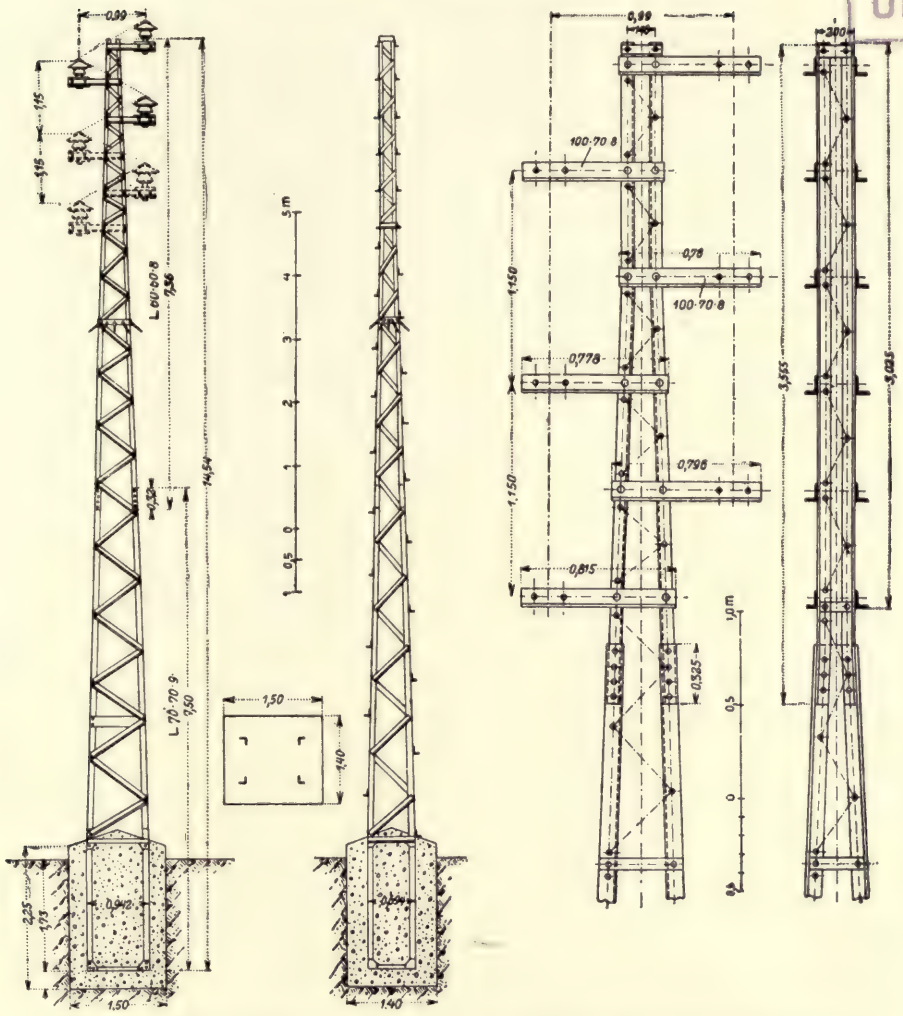


FIG. 11.—Type of Tower used in 50,000-volt Italian Transmission System.

1.22 pounds per linear foot; four-wire circuit No. 2, one-fifth inch diameter, area 1,000,000 cm., weight 3.55 pounds per linear foot; three wires, circuit No. 3, each 0.165 inch diameter, area 27,225 cm., weight .074 pound per linear foot, together with one-half inch coating of ice on all wires. The wind pressure is 30 pounds per square foot on the surface of the pole, and on all wires covered with one-half inch coating of ice. Unit stresses: Tension, 30,000 pounds per square inch net section;

$$I = \frac{\frac{30{,}000 \text{ pounds}}{L^2}}{125\, r^2}$$

the compression is per square inch cross section; shear on rivets 22,500 per square inch; bearing on rivets, 45,000 pounds per square inch; maximum bending moment on pole, 2,910,000 inch-pounds; maximum overturning moment of pole, 3,340,000 inch-

pounds. The painting is one coat of New York Central standard red lead paint on each surface in contact before assembling, and one coat on the entire pole before leaving the shop. Before erection two heavy coats of New York Central asphaltum varnish are added."

Luzerne Tower. A type of recent Swiss transmission line construction is given in Fig. 9, and is used in connection with the 27,000-volt line at Luzerne, Switzerland.[1] The towers are about 45 feet high measured from the ground up to the lower insulator. As will be seen in detail, Fig. 10, the insulators are mounted on vertical oak members carried by transverse channels and are 3.3 feet apart on the leg. The insulators are fastened to galvanized iron pins by hemp, linseed oil, and shellac. To prevent a line from dropping to the ground, guard angles are provided. Owing to adverse conditions, several of the towers had to be placed on a cantilever construction overhanging the lake as seen in Fig. 9.

For this purpose a cantilever structure had to be embedded in a heavy concrete block, in order to protect the cantilever and the tower from boulders coming down the mountain slope; heavy masonry abutments were placed on top of the concrete block; a passageway is provided to reach the tower. The total length of the cantilever is about 30 feet. The spacing of the cantilever poles is 400 feet, while the normal spacing for the land towers is about 200 feet.

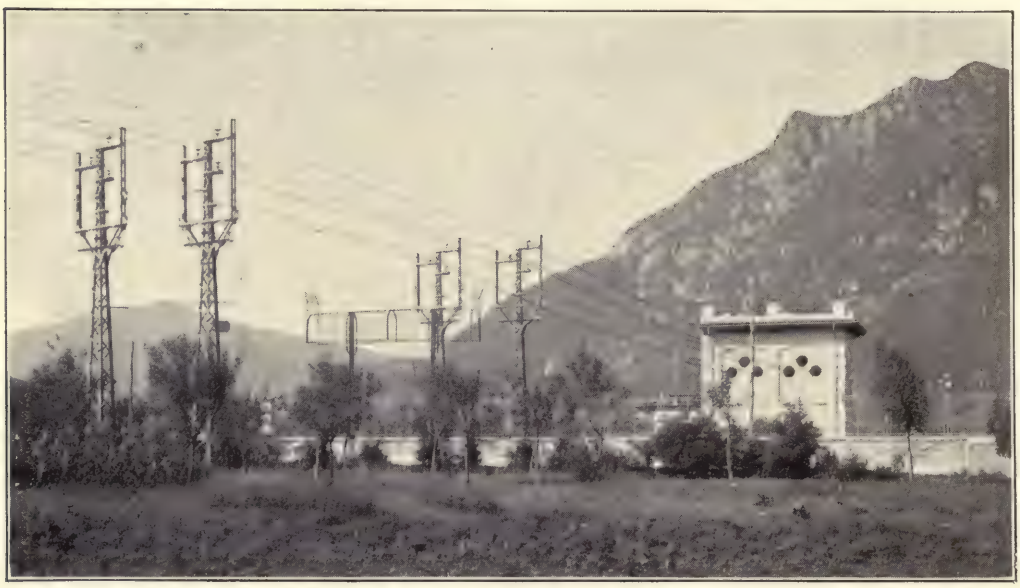


FIG. 12.—Highway and Telephone Crossing for 50,000-volt Line Near Lecco, Italy; also Section Switch House.

Brusio Tower. The latest and most prominent transmission line is that of the Brusio Plant, Switzerland, transmitting 50,000 volts for some 88.5 miles in the

[1] The 27,000-Volt Transmission System of the Obermatt Power Plant, Switzerland. *Electrical Review*, June 13, 1908.

northern part of Italy. Duplicate parallel lines (13 to 16.5 feet apart) run the entire length of the line. As they run over mountains and valleys of great variation in altitude, and owing to great difference in temperatures, frequent storms and atmospheric discharges, the peaks of the mountains were avoided.

The standard tower (see Fig. 11) is of angle iron lattice construction, and has brackets to accommodate two 3-phase circuits. Each cable consists of nineteen 2.6 mm. copper wires, the total diameter being 14 mm. (about 0.5 inch). The insulators are of the two-petticoat type, and are, according to Swiss practice, mounted on wood, carried on steel brackets. The tower is about 40 feet high from the ground to the lowest insulator, and spaced on the average, 393 feet; the longest span being 1280 feet, for which special towers were employed. All towers are set in concrete, and designed for a wind pressure of 70 miles an hour, allowing a stress of 17,000 pounds; the stress of the copper cables is 8500 pounds per square inch, accommodating a temperature change of 120° F.

Of the 3100 towers erected, there are only four different types employed, weighing from 1250 to 2500 pounds, and cost on the average, $80 each, including foundation and erection. The insulators cost $2.60 each, including mounting and the wooden blocks. At present, each line carries only one circuit, amounting to 900 gross tons of copper; the laying of same cost $28 per mile of transmission.

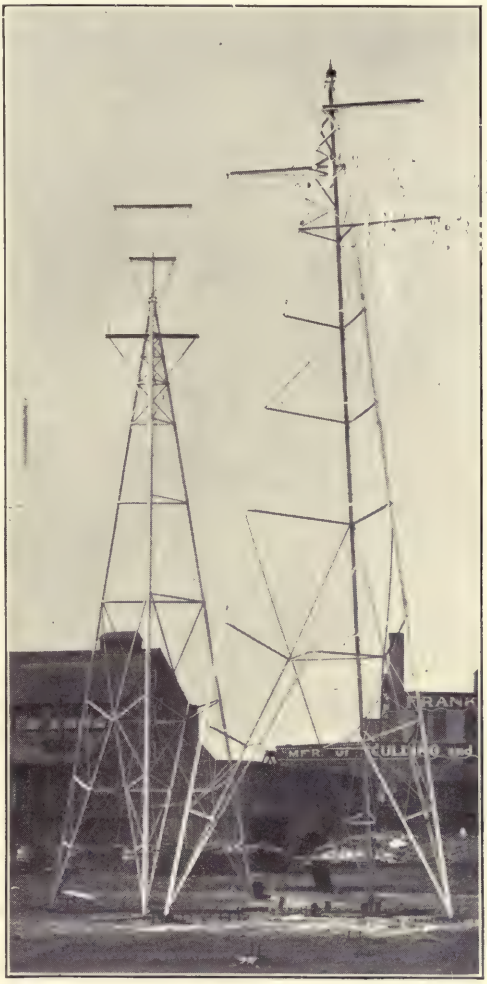


FIG. 13.—Aermotor Towers. At the Right a Medium Weight Tower for Suspended Insulators for the 110,000-volt Transmission System of the Grand Rapids-Muskegon Power Co., Mich.

Suspended Insulator Towers. All the above-discussed towers are for pin insulators; the suspended type of insulators requires a change in the brackets of transmission towers.[1] Types of such towers have been constructed by the Aermotor Company for the Grand Rapids-Muskegon Power Company;[2] they are from 40 to

[1] Some New Methods in High Tension Line Construction, by H. W. Buck. *Am. Inst. of E. E.*, June, 1907.

[2] The 100,000-Volt Steel Tower Line of the Grand Rapids-Muskegon Power Company. *Electrical World*, Nov. 2, 1907.

60 feet high and spaced about 500 feet apart. Each leg is anchored to a 3-inch angle 7 feet 10 inches long, set in concrete to prevent corrosion, except for about 10 inches at the bottom, which is left bare to provide an effective ground. Stranded copper cables with hemp centers, and having a conductivity equal to No. 2 solid wire, are suspended from brackets by means of 5 disk link insulators. The steel angles, to which the links of the towers are anchored, were set in concrete at a mixing plant at one end of the line and afterwards transported to the points needed. Each complete anchor weighs about 275 pounds. The concrete envelope is elliptical in section, the axes of the ellipse being 4.5 inches and 6 inches respectively. One 3-inch 4-pound steel channel and several short reinforcing rods were fastened horizontally near the bottom of each main angle as anchors. These channels and rods also were set in concrete disks, sheet-iron molds being used for the purpose.

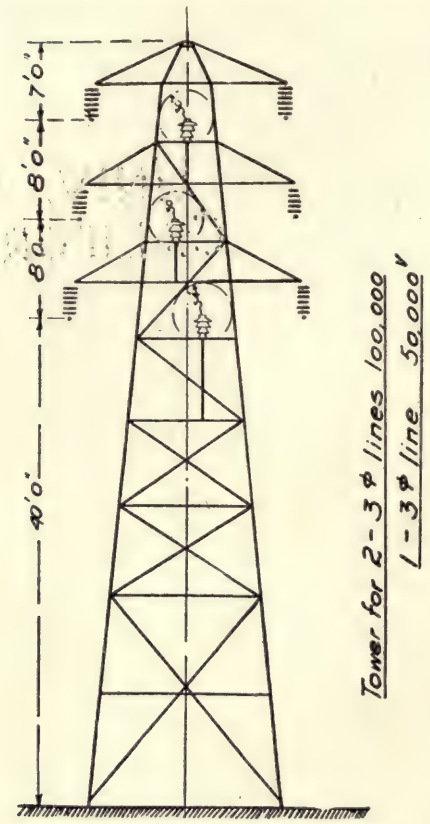


FIG. 14.—Type of Tower for Suspended Insulator, Southern Power Co., Charlotte, N. C.

Economical Spans. In laying out a transmission line it is of foremost importance first, to find out the most economical span, that is, after the size of the conductors has been calculated, not omitting the line loss; the next step is to ascertain the proper spacing. Having determined from the foregoing chapter the necessary cross section of copper conductor, the choice of material, whether copper, aluminum, or steel conductors should be used, must be decided.

TABLE I.—TENSILE STRENGTH AND CONDUCTIVITY OF CONDUCTORS.

Material.	Tensile strength, pounds per square inch.	Conductivity.
Copper...	55,000	100
Aluminum..	28,000	62
Steel..	100,000	12

In the foregoing table the conductivities and tensile strengths of conductors for high tension transmission lines are given; in connection with same the market price of the materials must be considered, especially those of copper and aluminum which vary greatly. From this and in conjunction with the design of the tower the most economical span can only be determined by making comparative estimates.

Line Stresses. The following example, by B. Wiley, illustrates a method for calculating the stresses on steel towers.[1] This problem was worked out for a span at the Homestead Steel Works, Pennsylvania, to cross the Monongahela River. The dimensions and other data are given in the illustration and calculations.

The conditions that form the basis of the calculations are as follows: Line voltage, 250; load to be carried, 800 amperes; drop of voltage permissible, 40 volts; necessary size of copper conductor, 1,000,000 circular mils; necessary size of aluminum conductor, 1,600,000 circular mils (duplicate lines of 800,000 circular mil cable were used for convenience of construction); maximum sag allowable at 212° F., 35 feet; maximum wind probable pressure, 40 pounds per square foot; minimum temperature, 20° F.; probable ice coating, one-fourth inch thick. The tensile strength of hard drawn aluminum wire is 35,000 pounds per square inch; its conductivity, 63, as compared with copper at 100; and the coefficient of expansion, .0000231 per degree Fahrenheit.

When a wire is suspended between two supports it takes a curve known technically as the catenary. In the case at hand the catenary comes very close to the parabola, which gives the following relations:

$$T = \frac{L^2 w}{8\,d}.$$

where T = tension in cable at ends,
L = length of span in feet,
w = weight per foot of wire,
d = the central deflection in feet.

Obviously T will be a maximum when w is at its maximum and d at its minimum. The wire will have its greatest weight per foot when coated with ice and is withstanding a heavy wind pressure; and the deflection will vary directly as the temperature.

The weight of 1 foot of 800,000-centimeter A1 cable	=	.736 pound
The weight of one-fourth inch ice coating per foot	=	.389 pound
Total weight per foot	=	1.125 pounds

Taking the wind pressure at 40 pounds per square foot and as acting on the cross-section of ice covered wire, the pressure per foot is 4.166 pounds. As this force acts at right angles to the weight, the resultant force $= \sqrt{1.125^2 + 4.166^2} = 4.31$ pounds, which may be considered the maximum for w.

For the catenary curve, $L' = L + \frac{8\,d^2}{3\,L}$,

where L' = actual length of cable,
L = length of span,
d = central deflection.

Transposing, $d = \sqrt{\frac{3\,L\,(L' - L)}{8}}$.

[1] A Long Span Transmission Line, by B. Wiley. *Electrical World and Engineer*, April 16, 1904.

From these two formulæ d can be figured for any temperature, the initial sag being 35 feet at 212° F. The following table gives the sag for temperatures between 212° F. and minus 20° F.:

TABLE II. — SAG AT DIFFERENT TEMPERATURES.

Temperature, degrees F.	Deflection, feet.	Temperature, degrees F.	Deflection, feet.
212	35.0	90	27.1
200	34.7	80	26.4
190	33.8	70	25.6
180	33.2	60	24.9
170	32 5	50	24.1
160	31.8	40	23.3
150	31.2	30	22.5
140	30.5	20	21.7
130	29.9	10	20.9
120	29.2	0	20.1
110	28.5	−20	19.2
100	27.8	−20	18 3

Substituting in equation (1) the values

$$w = 4.31 \text{ pounds (the maximum weight)},$$
$$d = 18.3 \text{ feet (minimum deflection)},$$
$$L = 1000 \text{ feet},$$

$$T \text{ (the maximum tension)} = \frac{1000^2 \times 4.31}{8 \times 18.3} = 29{,}400 \text{ pounds.}$$

The sectional area of 800,000-C.M. cable is .8 square inch, giving a tensile strength of .8 × 35,000 = 28,000 pounds per cable.

Comparing this result with the maximum tension, 29,400 pounds, it is seen that the line will not stand the severe conditions as set down. To relieve the strain, the line should be lengthened in the fall and, to prevent excessive sag, taken up again in the spring.

Suppose a range of temperature from 60° F. to − 20° F. be taken for the winter. Then the line could be allowed a drop of 35 feet at this maximum temperature, which, by reference to the table, would make the equivalent sag at − 20° F. 28.4 feet.

Substituting in formula (1),

$$T = \frac{1000^2 \times 4.31}{8 \times 28.4} = 19.000 \text{ pounds},$$

or the one setting would give a safe tension on the cable for the conditions noted, though for severe conditions it would be well to give the maximum drop of 35 feet, as the adjustment requires only a few minutes' work.

As an example, the maximum strain per cable is 19,000 pounds, or per tower, 4 × 19,000 = 76,000 pounds. The horizontal component due to the wind pressure is transmitted to the foundations and the direct pull to the steel brace rods behind.

TRANSMISSION LINE TOWERS AND ECONOMICAL SPANS.[1]

For any given transmission line there is a certain length of span which is most economical. A determination of what the economical span is, in any case, can only be made by obtaining data showing the variation of each item of cost which changes with the length of span. In a steel-tower line the cost of the tower is probably the most important among those items which vary with the length of span. As the span is made longer, the towers must be made higher and stronger. The purpose of this paper is to describe a method by which the relation between the height, strength, and cost of a tower of given form may be expressed. The application of this method to the problem of fixing the economical span will also be shown.

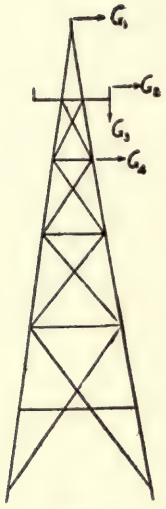


FIG. 1.

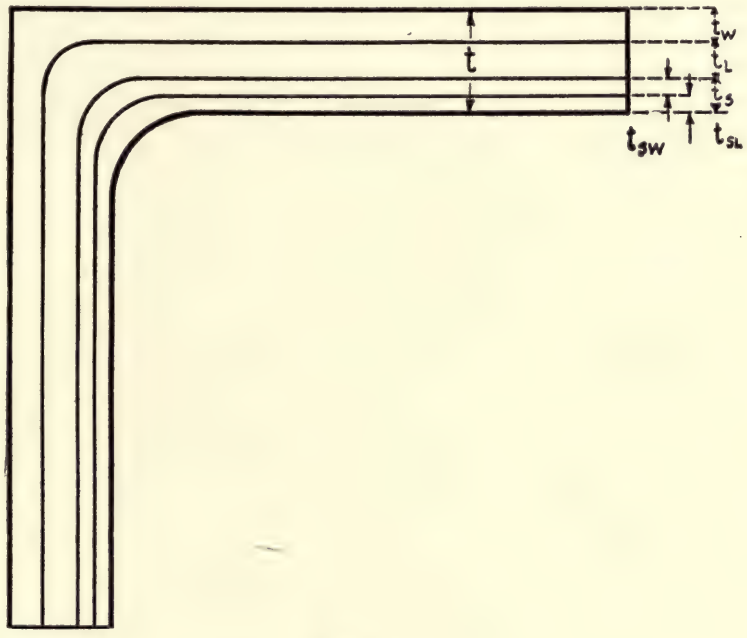


FIG. 2.

A transmission tower has, in general, three duties to perform:

1. It must have strength to resist wind pressure on its various members.

2. It must have strength to withstand certain external loads due to cables, guys, etc.

3. It must have strength to sustain its own weight.

The weight of a given transmission tower may therefore be considered to be made up of three components, each component corresponding to one of these sources of stress. The following equation may then be written for the weight of the structure shown in diagram in Fig. 1,

$$W = W_w + W_L + W_s \qquad (1)$$

in which W = total weight.

[1] A paper by D. R. Scholes. Am. Inst. of E. E., Niagara Falls, N.Y., June 26, 1907.

W_w = weight necessary to provide strength against wind pressure.
W_L = weight necessary to provide strength against external loads.
W_s = weight necessary to enable the structure to sustain its own weight.

Assume that the structure shown in Fig. 1 has been designed for a certain wind pressure, and for certain external loads of given amount and manner of application. Each member in the structure may be considered to involve three components of thickness, each component corresponding to one of the three general sources of stress. In determining the value of W_w, the stress in each member resulting from wind pressure alone would first be computed; with this as a basis, the component of thickness of each member necessary to sustain the stress due to wind pressure alone would then be calculated. Having determined the component of thickness of each member corresponding to the stated wind pressure, the value of W_w would follow directly. A similar method would be used in finding W_{sL} and W_s.

This method will, perhaps, be made more clear by referring to Fig. 2, which shows in cross section one of the members of the tower of Fig. 1.

In the figure,

t = total thickness,
t_w = thickness corresponding to wind pressure,
t_L = thickness corresponding to external loads,
t_s = thickness corresponding to weight of structure,
t_{sw} = thickness corresponding to component W_w of the weight of the structure,
t_{sL} = thickness corresponding to component W_L of weight of load.

It is seen that $$t = t_w + t_L + t_s \qquad (2)$$
and $$t = t_w + t_L + t_{sw} + t_{sL} \qquad (3)$$
since $$t_s = t_{sw} + t_{sL}.$$

The thickness of any other member of the tower may be considered to be divided up into parts in the same manner. Since t_s is divided into the parts t_{sw} and t_{sL}, a corresponding division may be made in the term W_s of equation (1) which gives

$$W = W_w + W_L + W_{sw} + W_{sL}, \qquad (4)$$

where W_{ws} = weight necessary to provide strength to sustain W_w and W_{sw}, and W_{sL} = weight necessary to provide strength to sustain W_L and W_{sL}.

The structure shown in diagram in Fig. 1 involves members of three general kinds; namely, beams, struts, and tension members.

The bending moment produced in a given beam by a given load W may be expressed by the equation

$$M = CWl, \qquad (5)$$

M = maximum bending moment,
l = distance between supports,
C = constant, dependent on the manner in which the load is distributed. The relation between the bending moment and the stress in the most remote fiber of the beam is given by the equation

$$M = \frac{PFk^2}{e}, \qquad (6)$$

M = bending moment,
P = stress per unit area in most remote fiber of beam,
F = cross-sectional area of beam,
k = radius of gyration of beam section,
e = distance of most remote fiber from neutral axis.

Combining these two expressions, the equation

$$W = \frac{P'Fk}{Cle} \tag{7}$$

is obtained, which gives the load which the beam will carry, P' being the ultimate strength of the material in the beam.

Now if k is the radius of gyration of a given figure, the radius of gyration of a second figure similar to the first but of different size is equal to nk, n being the ratio between corresponding linear dimensions of the two figures.

If, therefore, a second beam be considered, exactly similar to the first, but of different size and length, n being the ratio between corresponding linear dimensions of the two beams, the load which this second beam will carry is

$$W_2 = \frac{Pn^2Fn^2k^2}{Cnlne} = n^2\,\frac{PFk}{Cle}, \quad \text{and} \quad \frac{W_2}{W} = n^2. \tag{8}$$

Expressed in words, this relation may be stated as follows:

The load which a beam of given form will carry varies as the square of its linear dimensions.

The strength of a strut against compressive stress is given by Rankine's formula:

$$W = \frac{P'F}{1 + C\frac{l^2}{k^2}}, \tag{9}$$

W = ultimate strength of strut.
P' = ultimate compressive strength of material.
F = cross-sectional area.
l = length.
k = radius of gyration.
C = constant, depending on kind of material.

And the strength of another strut, exactly similar to the first but of different size and length, n being the ratio between corresponding linear dimensions of the two struts, is

$$W_2 = \frac{P'n^2F}{1 + C\frac{n^2l^2}{n^2k^2}} = n_2\,\frac{P'F}{1 + C\frac{l^2}{k^2}} \quad \text{also} \quad \frac{W_2}{W} = n^2. \tag{10}$$

Expressed in words, this relation may be stated as follows:

The load which a strut of given form will carry, varies as the square of its linear dimensions.

The strength of a tension member is directly proportional to its cross-sectional area; that is, it varies as the square of its linear dimensions.

An investigation of the action of a member subjected to torsional loads, similar to those just made for beams, struts, and tension members, would show a like relation; that is, the load which a member of given form subjected to torsion will carry, varies as the square of its linear dimensions. This investigation is not undertaken here, however, because members of this character are little used in transmission towers.

Returning to the structure shown roughly by Fig. 1. It is usually assumed that the actual pressure on any part of such a structure, produced by a wind of given velocity, is directly proportional to the exposed area of that part. Now the exposed area of any part is, in general, dependent on its length and breadth, but not upon its thickness. It therefore follows that if the structure shown in Fig. 3 is geometrically

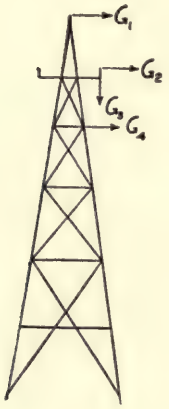


FIG. 3.

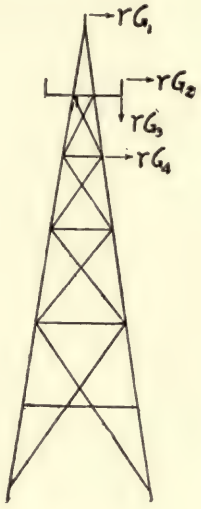


FIG. 4.

similar to that of Fig. 1, in every respect except the thickness of its parts, and is of different size, the ratio between corresponding linear dimensions being n, the load produced on any part of the second structure by a wind of given velocity is equal to n^2 times the load produced on the corresponding part of the first structure by the same wind. It also follows that the stress in any member of the second structure under these conditions, due to wind pressure, is equal to n^2 times that in the corresponding member of the first structure.

For the structure of Fig. 3,

$$W' = W'_{W} + W'_{L} + W'_{SW} + W'_{SL} \tag{11}$$

and

$$t' = t'_{W} + t'_{L} + t'_{SW} + t'_{SL} \tag{12}$$

From the foregoing discussion of the relation between the size and strength of beams, struts, etc., of given form, it is evident that

$$t'_w = nt_w \tag{13}$$

and

$$W'_w = n^3 W_w \tag{14}$$

both structures being calculated for the same wind pressure.

Again referring to the equation for beams,

$$W = \frac{P'Fk^2}{Cle}, \quad \text{or} \quad F = \frac{WCle}{P'k^2}. \tag{15}$$

It is evident that if k and e can be kept constant, the sectional area which a given beam must have to sustain a load distributed in a given manner varies directly as the load and directly as the length of the beam. The sections commonly employed as beams are angles, channels, and I-sections. By reference to any handbook of such sections it will be seen that for any of these sections of a given nominal size the area of the beam may vary considerably without producing more than a negligible change in the value of k or e.

Hence, if after the nominal size of a beam has been determined, it is desired to vary either the load or the length of the beam, the sectional area should be made to vary directly as the load and directly as the length of the beam.

From the formula for columns,

$$W = \frac{P'F}{1 + C\frac{l^2}{k^2}} \quad F = \frac{W\left(1 + C\frac{l^2}{k^2}\right)}{P}, \tag{16}$$

it is seen that, if the ratio l/k is kept constant, the strength of the column is directly proportional to its cross-sectional area.

From the nature of a tension member, its strength is proportional to its sectional area.

Again refer to Fig. 1. It is assumed that this structure is subjected to the loads G_1, G_2, G_3, etc., these loads being placed upon it through cables, guys, or the like. The application of each of these loads will, in general, produce certain stresses in each of the members of the structure. The stress in a given member produced by a given load will be directly proportional to the load, and the magnitude of the stress will depend on the particular position which the member occupies. If a certain system of loads, as G_1, G_2, G_3, and G_4, is applied to the structure, the resultant stress in any given part may be considered to be made up of the components AG_1, BG_2, CG_3, and DG_4 — A, B, C, and D being constants. Also, if each of the loads is multiplied by a factor r, the resultant stress in any member will also be multiplied by that factor.

Moreover, if a system of loads as G_1, G_2, G_3, etc., be similarly applied to another structure geometrically similar to that of Fig. 1, but of different size, the stress pro-

duced in a given member of the second structure by these loads will be equal to that produced by them in the corresponding member of the first structure. In other words, the stress in any member is dependent only upon the geometrical form of the structure and the amount and manner of application of the loads producing it, and is not affected by the actual size of the structure.

Let the structure indicated in Fig. 4 be geometrically similar to that of Fig. 1 in all respects except the thickness of its members. Let the system of loads, rG_1, rG_2, rG_3, and rG_4, applied to this structure be similar to that applied to the structure of Fig. 1, but of different magnitude, the ratio between corresponding loads being r. Also let the structure of Fig. 4 be designed for a different wind pressure from that of Fig. 1, the ratio between the wind pressures per unit area in the two cases being p.

For the structure of Fig. 4,

$$W'' = W''_{W} + W''_{L} + W''_{SW} + W''_{SL} \tag{17}$$

$$t'' = t''_{W} + t''_{L} + t''_{SW} + t''_{SL} \tag{18}$$

In view of the relations pointed out between the length, sectional area, and strength of the various kinds of members involved in the structures, it follows that

$$W''_{W} = n^3 pW_{W} \tag{19}$$

$$W''_{L} = nrW_{L} \tag{20}$$

$$W''_{SW} = n^4 pW_{SW} + \ldots . \tag{21}$$

$$W''_{SL} = n^2 rW_{SL} + \ldots . \tag{22}$$

To make equations (21) and (22) strictly accurate, terms must be added to represent the weight added to provide for the strength necessary to take care of each individual increment of weight. This will involve a convergent infinite series in each case. All terms of these series, except the first, are, however, relatively unimportant and will therefore be neglected.

Substituting in equation (17)

$$W'' = n^3 pW_{W} + nrW_{L} + n^4 pW_{SW} + n^2 rW_{SL}. \tag{23}$$

This is a general equation, and, given the values of W_{W}, W_{L}, W_{SW} and W_{SL} for the structure of Fig. 1, it makes it possible to calculate the weight of the structure of Fig. 4 without going through the routine of calculating the stresses in each member and the sizes and weights of the parts necessary to carry these stresses.

The application of this formula to the problem of fixing the economical span for a given transmission line is obvious. A tower for a given length of span would be designed to furnish the strengths necessary for that span. The design would be made in accordance with the manufacturing facilities available for producing the structures. The stresses in each member would be carefully calculated and the values of W_{W}, W_{L}, W_{SW} and W_{SL} found for the structure. Having found these values, the weight of any similar structure for any length of span could be determined by substitution in equation (23).

It is to be observed that this method of treating the case assumes that both wind

loads and external loads are to be applied to the structure simultaneously. This is usually the case. In other cases, however, the method to be pursued would be similar, but modified to suit the peculiarities of the case.

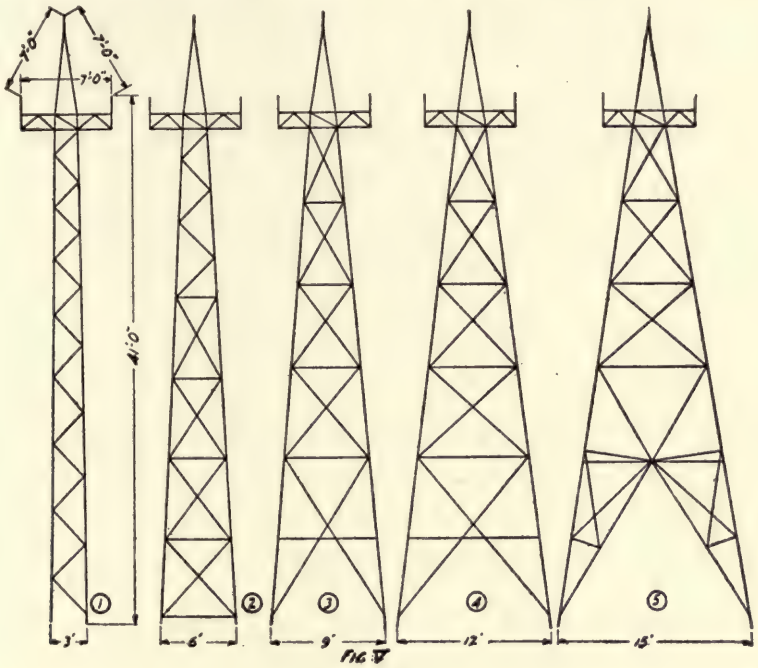


FIG. 5.

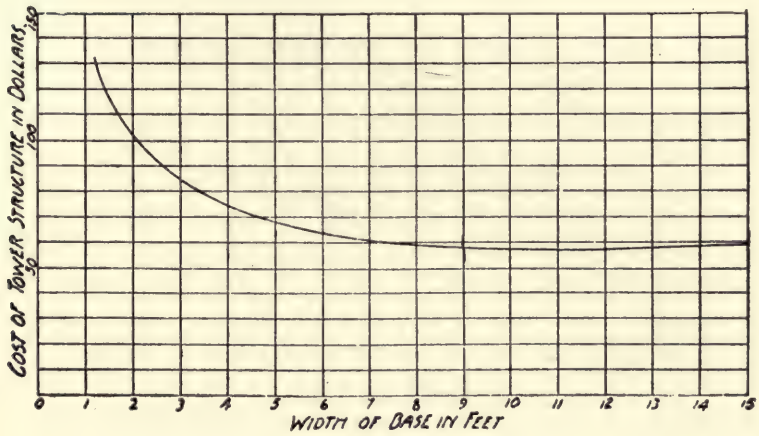


FIG. 6.

It is also to be borne in mind that formula (23) contemplates that variations in the cross section of any member will be made in such manner that the radius of gyration of the section will be kept proportional to n in every case, and also that no appreciable variation from geometric similarity will occur. These assumptions do not involve any appreciable inaccuracy within the range of ordinary practice.

Before the problem of providing steel towers for supporting the cables of a given transmission line can be considered, the general features of the line, its voltage, size of conductor, etc., must be fixed. To show the application of the formula just developed, the following set of general assumptions has been selected as a working basis, and it is believed that they are in accord with average high-grade practice.

General Assumptions. System: three-phase alternating current.

Conductor: 400,000 circular mils stranded copper. Cross-sectional area 0.3145 square inch. Outside diameter 0.73 inch. Weight per foot 1.22 pounds.

Spacing: 7-foot delta, for 500-foot span.

Minimum clearance: 30 feet between ground and lowest conductor at center of span.

Temperature range: 40° F. to 110° F.

Sleet: 0.5 inch all around cables. Diameter of conductor with sleet 1.73 inches. Weight per foot with sleet 1.98 pounds.

Wind pressure: 30 pounds per square foot normal to plane surfaces.

Test factor of safety: 2.

It is further assumed that at occasional intervals along the line, the structures will be stayed by guy cables in the direction of the line, and that the cost of such staying will not vary with the length of span. To provide in all structures a certain amount of strength against loads on the insulators, in the direction of the line, it is assumed that in the tower for the 500-foot span, an unbalanced test load of 2000 pounds will be applied to the top of each insulator pin in a horizontal direction parallel to the line.

In explanation of the term "test factor of safety," it may be said that it has become usual for purchasers, in issuing specifications for towers, to require that the structures must show, under actual test, their ability to withstand the loads due to the assumed wind pressures, weights, etc., with a certain factor of safety. In calculating the load to be applied to the top of an insulator pin, for instance, to test it for strength against wind pressure on cables, the effective area of the cable with sleet would be multiplied by the stated wind pressure and by the factor 2. The load thus obtained would then be actually applied to the structure, and its acceptance would depend upon its ability to withstand such tests. In order that the structure may have a certain margin of strength over and above that actually required to withstand tests based on a test factor of safety of 2, the sizes of the members will be calculated with reference to a factor of safety of 2.5 based on ultimate strength.

In determining the sag corresponding to each length of span, reference has been had to the curves given in Fig. 9, calculated by Mr. Ralph D. Mershon, and here reproduced through his courtesy. These curves indicate in each case the sag for maximum temperature, this sag being so determined that, when under minimum temperature and maximum wind and sleet loads, the conductor will not be stressed beyond its elastic limit.

With the foregoing set of conditions at hand, computations have been made of the cost of each of a series of structures for a 500-foot span, these structures being of

varying width of base but uniform in height. The purpose of these computations is to show the relation between the width of base and cost for such structures, and to obtain an indication as to what ratio between height and width of base is most economical. This series of structures is shown in diagram in Fig. 5. A curve is given in Fig. 6 showing the relation between the width of base and the cost per structure. The cost of each structure has been figured on a basis of $4.50 per 100 pounds delivered in the field. The construction involves standard angle and flat steel sections, standard butt-weld pipe, and some simple forgings. It has been

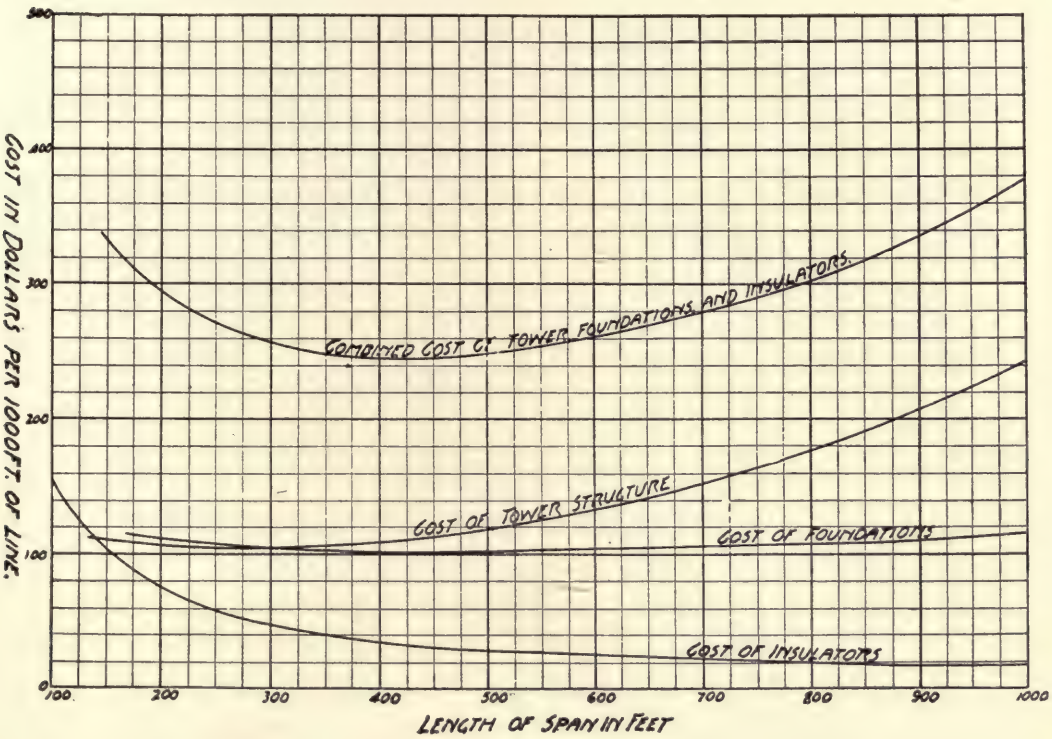


FIG. 7.

assumed that all parts would be properly galvanized, so no limitation has been made as to the minimum thickness of material, it being simply required that the members be of sufficient strength to meet the conditions laid down. The construction admits of shipment knocked down and bundled, and it is believed that the figure $4.50 per 100 pounds for structures of this class delivered in the field, is quite safe.

It will be seen, by reference to the curve in Fig. 6, that the cost of the structure alone is least when the ratio of width of base to height is about 1 to 4. This conclusion has reference, of course, only to the span of 500 feet and to the conditions and type of construction adopted.

The width of base of the structure has an important bearing on the cost of the line, aside from its effect on the cost of the tower structure itself, since it affects the cost of foundations, the cost of right of way, and the cost of assembling and raising the structure in the field. Now it is a difficult and uncertain matter to estimate the variation of cost of these items for a general case. Hence a determination of the economical width of base for certain assumed conditions would be of but little interest in the present connection.

Application of the Formula. The structure having a width of base equal to one-fourth its height has been selected as a basis for calculations of the weights of towers for longer spans. An investigation of this structure has been made to determine the values of W_w, W_L, W_{sw}, and W_{sL}, and the following values arrived at:

$$W_w = 383 \qquad W_{sw} = 34$$
$$W_L = 813 \qquad W_{sL} = 60$$

The table given below gives the results obtained by means of the formula for a series of towers similar to No. 4 in Fig. 5, but for spans up to 1000 feet. Since all towers in the series are to be for the same wind pressure, p is equal to unity in each case. Also, r is proportional to the length of span, since the external loads are due to wind pressure on the cables and the weight of the cables.

TABLE I.

Span.	Sag.	Height.	n	n^2	n^3	n^4	p	r	n^3pw_w	n^2rw_L	n^4pw_{sw}	n^2rw_{sL}	w''
200	2.0	32.0	0.780	0.608	0.475	0.370	1	0.4	182	254	13	15	464
300	4.5	34.5	0.832	0.692	0.576	0.479	1	0.6	221	406	16	25	668
400	7.5	37.5	0.915	0.837	0.766	0.701	1	0.8	294	596	24	40	954
500	11.0	41.0	1.00	1.00	1.00	1.00	1	1.0	383	813	34	60	1290
600	15.5	45.5	1.11	1.23	1.37	1.51	1	1.2	523	1082	52	89	1746
700	20.5	50.5	1.23	1.51	1.86	2.28	1	1.4	703	1405	78	128	2314
800	26.0	56.0	1.366	1.86	2.55	3.46	1	1.6	978	1778	118	179	3053
900	33.0	63.0	1.537	2.36	3.62	5.57	1	1.8	1386	2250	190	255	4081
1000	40.5	70.5	1.72	2.96	5.09	8.76	1	2.0	1950	2800	298	356	5404

These results are shown graphically in Fig. 7 by the curve which gives the relation between the length of span and the cost of towers per thousand feet of line. By properly representing to this same scale the cost of insulators, foundations, right of way, etc., per thousand feet of line, corresponding to the various lengths of span, and adding the corresponding ordinates of all these curves, a resultant curve will be obtained. This resultant curve will show the relation between the length of span and cost of those items which vary with the length of span, and it will therefore indicate the economical span for the assumed conditions.

A curve showing the cost of insulators per 1000 feet of line is given in Fig. 7, the insulators having been figured at $5.00 each, erected on the tower and with the conductor secured to them.

The curve in Fig. 7, showing the cost of foundations per 1000 feet of line, has reference to the type of foundation shown in Fig. 8, and to the following method of calculation.

It is a usual assumption that the strength of a foundation against a force tending to pull it out of the ground is directly proportional to the weight of the foundation plus the weight of earth contained in the figure *ABCD*.

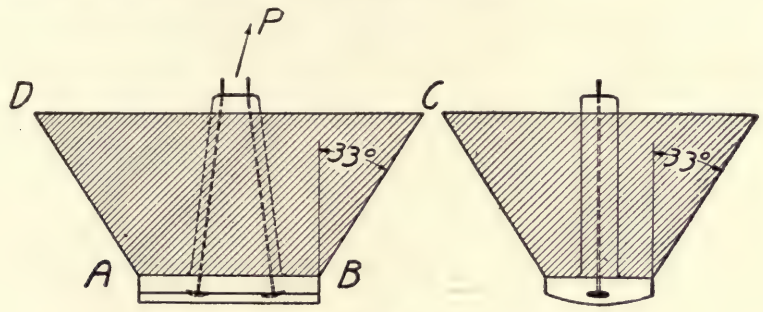


FIG. 8.

If the foundation in Fig. 8 has strength to resist a resultant force P, a second foundation, exactly similar to it but of different size, would have strength to resist the force n^3, pn being the ratio between corresponding linear dimensions of the two foundations. Now it seems fair to assume that the cost of such a foundation would vary directly as its volume. The cost of the foundation would therefore vary directly as the resultant force which it is capable of resisting.

Referring to some experiments made at Chicago on a foundation similar to that of Fig. 8, and to the records showing the actual cost of the foundation in the field, ready to receive the structure, the following basis for calculation was obtained:

Resultant force sustained by foundation	24,000 lb.
Cost of foundation	$15.25

By calculating the resultant force which would come upon the foundation from each of the structures given in Table I, and making the cost of foundation for each structure proportional to that force, on the basis of the data above given, the curve showing the foundation cost per 1000 feet of line given in Fig. 7 was obtained. It is to be observed that this curve is quite flat, indicating that the foundation cost does not vary to any great extent as the length of the span is varied.

The curve of combined cost of towers, foundations, and insulators was obtained by adding the respective ordinates of the curves giving the separate costs of these items. This curve indicates that, for the assumed conditions, a span of about 425 feet would be most economical.

It is to be observed that in the foregoing solution the determining factors are the tower cost and the insulator cost. As the price per insulator is increased, the econom-

ical length of span would be increased, and vice versa; in other words, the higher the voltage the longer the span should be.

For a low-voltage line the economical span would be somewhere between 300 and 400 feet, as far as the methods of calculation here employed can determine. Each structure in this case would, however, be a very light affair. It is probable that in the average case a somewhat longer span would be decided upon in order to give each structure greater individual strength and thus make it safer against damage due to external causes.

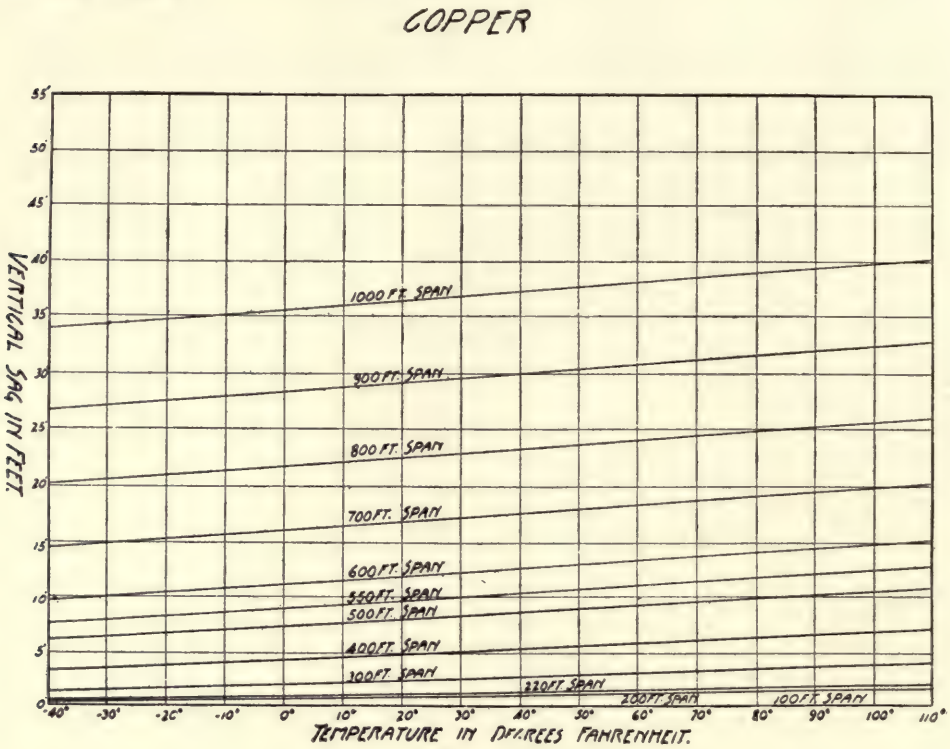


FIG. 9.

In case it is desirable to impose limitations of this sort, the formula must be modified accordingly, by subdividing the component of weight into parts; as, for instance, by letting

$$W_L = W_{G1} + W_{G2} + W_{G3} + W_{G4}$$

where W_{G1}, W_{G2}, W_{G3} and W_{G4} are components of weight corresponding to the loads G_1, G_2, G_3 and G_4 respectively.

These loads may then be made to vary at different rates, or some may be kept constant and the others varied in such manner as may be desired. Suppose, for example, it is assumed that each structure should have strength to resist the loads due to the breakage of any two conductors. These loads would be the same regardless of the length of span, whereas the loads due to wind pressure on the cables would vary according to the length of span.

These assumptions will, in general, tend to make the economical span longer.

INSULATORS.

Pin Insulators. With high-tension transmission systems multi-petticoat porcelain insulators are extensively used. However, recently a new type, known as the "link" insulator, has been developed. The petticoat types are made in several sections cemented together, and with exceptionally large sizes they are frequently cemented in the field. When this is done, care must be exercised to prevent the cement from being chilled while setting. The cement mixture must be a fine rich mortar free from impurities.

Porcelain for electrical purposes[1] is a mixture of ground flint or silicon dioxide and feldspar ($K_2O.Al_2O_3.SiO_2$), potassium aluminum silicate, raised to the vitrifying temperature, that is, to a temperature sufficiently high to melt the feldspar and permit it to unite the particles of flint into a perfectly homogeneous body of uniform electrical and mechanical strength.

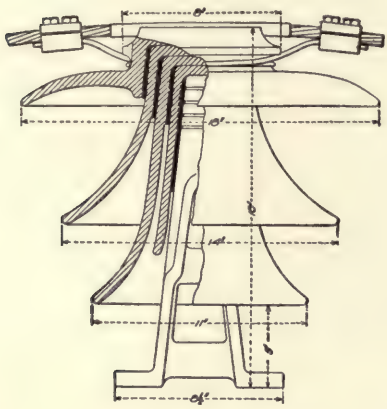


FIG. 1.—Insulator for 60,000-volt used on the Kern River Transmission System.

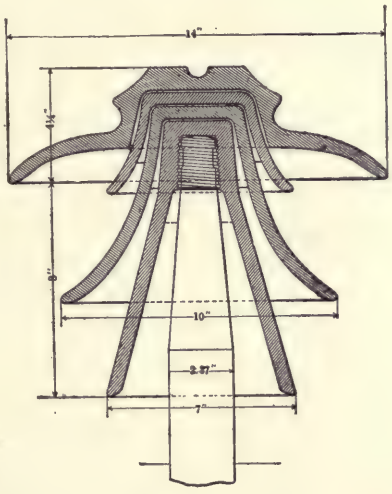


FIG. 2. — 50,000-volt Insulator used on the Taylor's Falls Transmission System.

Besides the electrical stresses, the insulators must be made strong enough to withstand mechanical stresses imposed on them by the span. Mechanically, insulators can be designed for any load by the proper disposition of material. Good electrical porcelain has a crushing strength in excess of 15,000 pounds, and tensile strength ranging between 1500 and 2000 pounds per square inch. Fig. 1 shows an insulator as installed at the Kern River Plant.[2] The specification called for a guarantee of a 100,000-volt test from the groove to the pin for half an hour, under a precipitation of 1 inch in 5 minutes, at an angle of 30 degrees from the vertical. The assembled insulator was required to withstand under a wet test a potential of 150,000 volts for 30 seconds, and the separate parts are guaranteed to withstand a voltage of 25 per

[1] "High Voltage Insulator Manufacture," by Walter T. Goddard. *Canadian Society of Civil Engineers*, Dec. 19, 1907.

[2] Kern River Plant No. 1. *Electrical World*, Aug. 31, 1907.

cent in excess of the normal proportion of over-voltage test. The insulators are guaranteed to withstand a side strain of 4000 pounds, and actually fail at approximately 9000 pounds.

A cross section of the insulator used on the Taylor's Falls 50,000-volt transmission system[1] is seen in Fig. 2. It is known as the S.W. No. 1, made by the Locke Insulator Manufacturing Company. It consists of four parts held together with neat cement. These insulators are shipped in crates assembled, but without pins. The crates were provided with holes just the size to take the pin. The cementing in of pins was done before the insulators were uncrated, the crate thus serving the purpose of a template to hold the pins in position while the cement dried. The insulator, as seen by the drawing, is 12¼ inches high by 14 inches in diameter over all. The four parts were tested before assembling with a 60-cycle, 200-kilovolt-ampere testing set. The top piece withstood a test pressure of 60,000 volts; the second shell 40,000 volts; the third shell, 50,000 volts; and the fourth inner shell or center, 50,000 volts. The assembled insulator without cement was tested at 120,000 volts.

The experience of noted Swiss and Italian engineers in the development of high-tension insulators is summed up in an article entitled, "Present Status of European Practice in Transmission Line Work,"[2] of which the following is an extract:

"The experiences of Mr. Charles Brown, one of the earliest workers in this field, and a pioneer of many of the more recent developments, gives a word of warning to those engaged in insulator testing, claiming that most insulators have a very pronounced fatigue effect. Though an insulator may stand a given tension for 15 minutes, it may possibly break down at this tension if it is maintained for two hours. He recalls the great difficulty always experienced in attempts to deduce reliable results from any testing, except actual use on the transmission line. He further states that very little trouble is experienced from heavy rainstorms or climatic conditions causing insulator breakdowns, the trouble being almost entirely mechanical and due to lightning. Such mechanical defects as have been experienced are thought to be due largely to the use of cement for connecting the petticoats of the insulators together, since great difficulty is experienced in obtaining a cement which does not swell with increase of temperature and thus fracture the insulator. In Switzerland, use is made of sulphur cement (when sulphur is used, the pins must be galvanized) and plaster of Paris, both of which have given satisfaction. The latter, however, being somewhat porous, must be varnished with shellac wherever it is exposed to the air at the outside of joints, etc.

"For fixing the pins of the insulators, tow or hemp is used, which is twisted around the end of the pin, the whole being then dipped in asphalt or shellac and screwed into the insulator. Mr. Brown states that no splitting or fracturing of insulators occurs with this method of fixing the pins.

"It is further stated that no good results have been obtained with the Fox cement, which is thought to have too high a coefficient of expansion, producing splitting

[1] The 50,000-Volt Line of the Taylor's Falls, Minneapolis, Power Transmission. *Electrical World*, Sept. 7, 1907.

[2] *Electrical World*, Dec. 22, 1906.

A.E.&M.
UNIV. OF CA

troubles. In this connection, however, it should be noted that somewhat thinner insulators are used in Switzerland than in Italy, and the engineers of the latter country have found very little trouble due to this cause.

" Other Swiss experts have referred to the difficulty in the manufacture of perfect insulators, pointing out that minute holes in the enamel in the surface which cannot be seen by the eye, may pass test, and then cause breakdown after some months' installation.

" Some again claim to have overcome the difficulty due to insulator splitting, by using no cement at all, the insulator being made in two or more pieces which are tested independently and then screwed together and the whole rebaked.

" They have also paid considerable attention to the exact shaping of the edges of the insulator petticoats, a rounded edge being considered very bad, since in a heavy rainstorm it will cause the water to run under and drop on the surface of the lower petticoats. They at present very much favor a petticoat slightly turned up near the edge to check the velocity of the running water and then dropping to a sharp point on the extreme edge, which seems to prevent this running under. By this means it is considered that the effect of rainstorms may be considerably reduced. For all transmission lines for electromotive forces of 40,000 volts and above, iron poles are preferred, and if the insulators have not more than two petticoats, wooden cross-beams are used; if three or more, then they are placed directly on the iron poles.

" In Italy, Mr. Guido Semenza, whose name is associated with the well-known Paderno transmission and numerous others throughout the country, referring to his early experiences, stated that on the Paderno line, after some experiment, his conical type of insulator was chosen and a triple petticoat was used; the line being, however, finally completed with two of these cemented together as one six-petticoat insulator, The dimensions of this were, height over all, 7 inches; diameter of petticoat, $6\frac{3}{4}$ inches. In other plants the Paderno type has been superseded by a much lighter insulator, but it has lately returned to favor and is in general use. The original Paderno insulator is shown in Fig. 3."

This type of insulator has also been installed on the 50,000-volt system of the Brusio plant. It is fastened to the pins by hemp and shellac as above described. The pins are mounted on wooden blocks, secured to the steel cross-arm.

On many European high-tension tranmissions systems, the insulators are made in one piece to eliminate cementing. Such insulators are employed on the 35,000-volt transmission system of the Urfttalsperre plant, Germany.

Suspension Insulators. A new type of insulator successfully used in recent practice is the suspension type. The advantages of this type over the pin insulator are given by Mr. Goddard as follows:[1]

"The reason for using suspended insulators is largely a matter of cost, since it is entirely possible to build porcelain insulators of the conventional type of sufficient size to successfully operate at any voltage, but the extreme height and diameter of

[1] High Voltage Insulator Manufacture, by Walter T. Goddard. *Canadian Society of Civil Engineers*, Dec. 19, 1907.

a pin-type insulator for 100,000 or 150,000 volts makes the cost prohibitive. A suspended type of insulator has several advantages which it is well to understand before going into details of design. Of paramount importance is the unit formation making it possible to increase the effective insulation whenever it is desired to raise the line voltage or wherever it seems desirable to present extra leakage surface because of

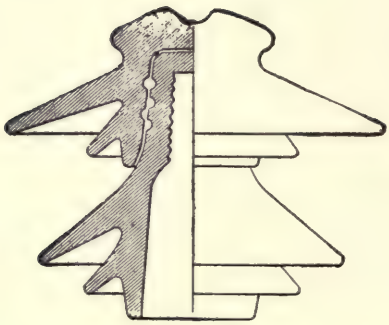


FIG. 3.—Paderno Type Insulator for 40,000 to 50,000 Volts.

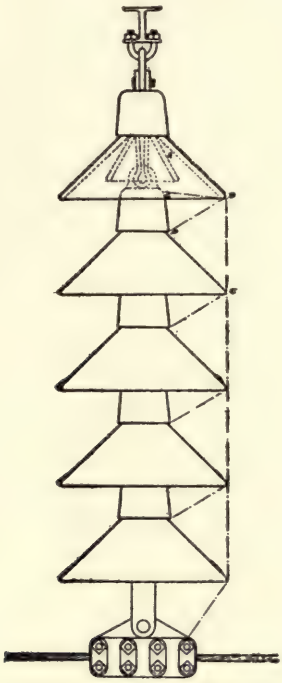


FIG. 4.—Suspended Insulator, showing the Progressive Breaking Down between the Beginning of Actual Leakage and the Maximum Arc.

salt fogs or smoke from railways and factories. Many lines start operation at much lower potential than designed for, because the initial load is light, and the potential need be increased only when regulation demands it. With the pin type of insulator there is no alternative but to invest at the start in the largest insulators which the line will ever need, whereas in the suspended form, additional units may be introduced whenever the growth of power business warrants an increase in potential. In the pin type of insulator the nearness of line wire and pin must always prove a weak point for lightning assault as well as an aggravator of line-charging current difficulties. The suspended type gets away from both difficulties by a wide separation of line conductor and supporting structure. Incidentally the position of the

conductor below the cross-arm permits the supporting structure to act as a lightning rod and so to relieve the line of much lightning stress.

" Mechanically, provision must be made to prevent the swinging conductor from coming too near the tower structure, but the extra length of cross-arm necessitated by this feature is more than compensated for in cost by the fact that there are no twisting strains upon the arm. Insulator unit formation presents another very positive advantage in the matter of breakage. When a shell of a pin-type insulator

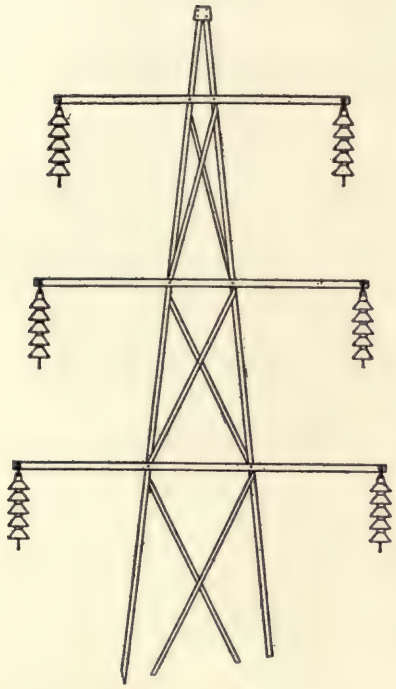


FIG. 5.—Method of Suspending Insulators.

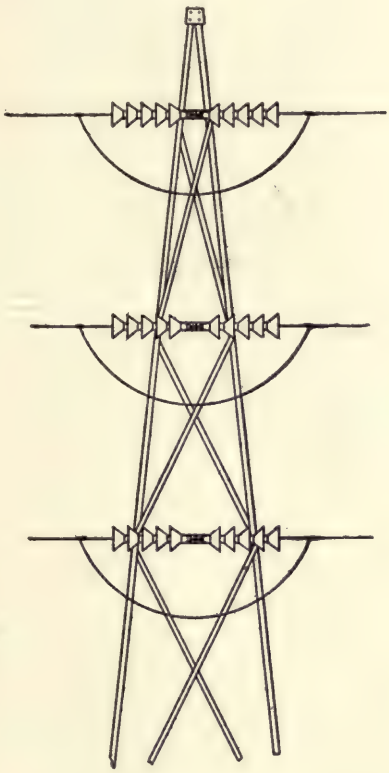


FIG. 6.—Detail of a Dead Ending.

becomes cracked or broken the whole device is rendered worthless, as it is utterly impossible to break the cement joint forming the bond between shells. Further, the cracking of a shell, especially an inner shell, may cause immediate shut-down, or at least shut-down during the first severe rainstorm. On the contrary, the breaking or cracking of one of the shells of a suspended-unit type insulator takes away but that one unit from the series; thus, in the case of a five-unit, 100,000-volt insulator, a broken unit reduces the total strength but twenty per cent.

"The underhung system of insulation works out with pleasing directness and simplicity, and its comparative cheapness argues for its wide adoption for the higher voltages. The cost of such insulators, as at present manufactured, ranges from $1.60 to $2.00 per unit, depending on the nature of the fittings.



FIG. 7.—Suspended Insulators as used in the 110,000-volt System of the Grand Rapids Muskegon Power Co., General Electric Co.

"At least two 14-inch units would be required for 60,000 volts, and as good 60,000-volt insulators can be secured for prices ranging from $1.70 to $2.30 each, the question of the use of suspended units for voltages below 75,000 to 80,000 is largely one of safety factor and investment.

"The foregoing has given little which could be used in the determination of the proper insulator to use for any particular voltage, and it is quite in point to add here, that every case is special. Insulators well suited to one locality are out of reason for use elsewhere. A single transmission line of less than 100 miles in length may easily pass from high, clear mountain air to foggy, smoky surroundings which are a constant menace to continuity of service.

Again, the cost of complete immunity may well be balanced against cost of possible shut-downs."

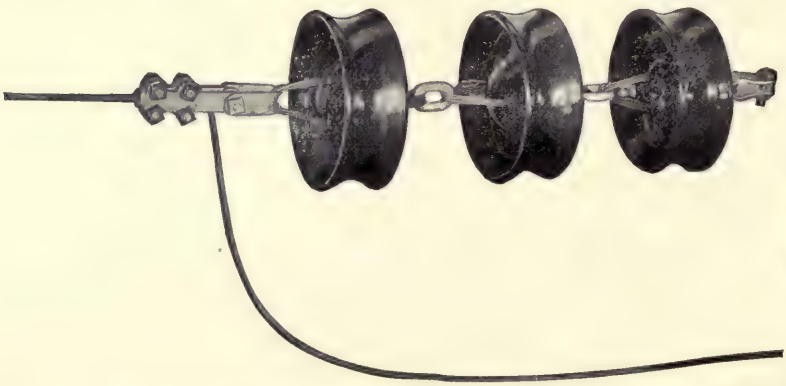


FIG. 8.—Dead-End Insulator of the Suspended Type. General Electric Co.

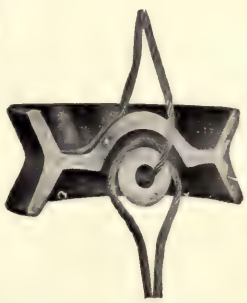
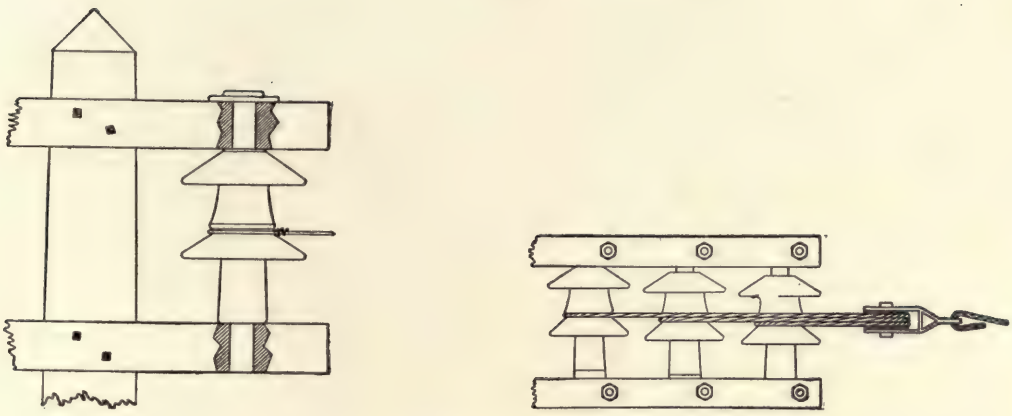


FIG. 9.—Single Desk of Suspended Insulator.

A detail of the Locke Suspended Insulator is given in Fig. 4, while two other illustrations give the method of application of same. The dead-ending scheme as proposed for all towers has the advantage that in case of a breakdown of a conductor



FIGS. 10 and 11.—Application of Cooke Strain Insulators.

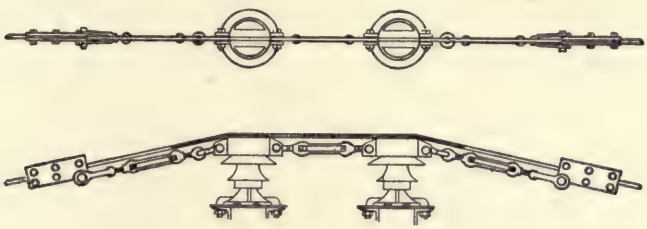


FIG. 12.—Diagram of Anchor Insulators.

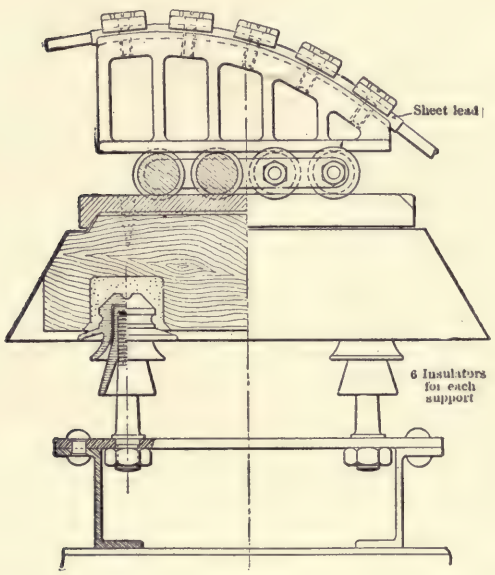


FIG. 13.—Insulating and Rolling Support for Long Spans, Tofwehult-Westerwik Transmission System, Sweden.

adjacent sections do not have to be slacked down in order to repair the break. The disadvantage is that the line conductor has to be cut up into sections, the current being by-passed by a loop or " jumper " as seen in the illustration.

A suspended type of insulator is used on the 110,000-volt transmission system of the Muskegon Grand Rapids Power Company. They are of the type described by Mr. Hewlett in his paper presented at the last convention of the American Institute of Electrical Engineers, at Niagara Falls, June 26, 1907. Figs. 7 and 8 show the construction of the members of this insulator. Five of these insulators are suspended in series to insulate the line. The diameter of each porcelain link is 10 inches, and the rated voltage that each link will withstand is 25,000, although the links arc over where wet at approximately 60,000 volts each. Fig. 9, while showing the interior

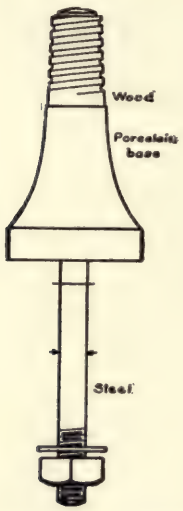


FIG. 14.—Porcelain Base Insulator Pins.

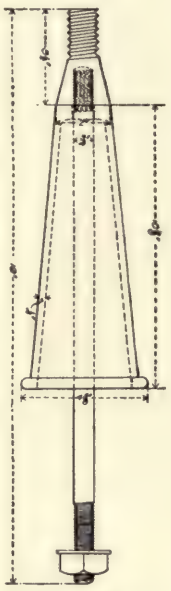


FIG. 15.—All Steel Insulator Pins.

construction, also shows the form of petticoat on the insulator used in a horizontal position as a strain insulator at curves and at intervals to anchor the line. The spans of this line are on the average about 150 feet. The conductors consist of stranded copper cables with hemp centers, having a conductivity equal to No. 2 solid wire. This line was designed for 100,000 volts, but recently the voltage has been raised to 110,000.[1]

Strain Insulators. Strain insulators must be placed at the beginning and end of lines, and at all sharp turns to take up the pull of the spans which ordinary insulators cannot stand. Such insulators as seen in Figs. 10 and 11 are usually held at top and bottom.

Two or more ordinary insulators, when used in connection with an anchoring

[1] Editorial, *Engineering Record*, Aug. 15, 1908.

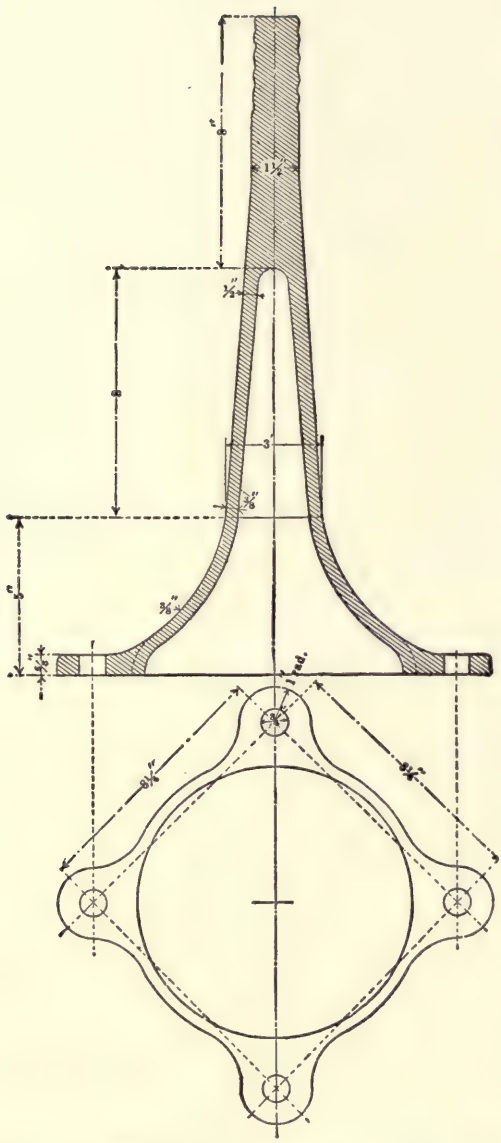


FIG. 16.—Detail of Iron Insulator Pin, used for Insulators seen in Figs. 17 and 18.

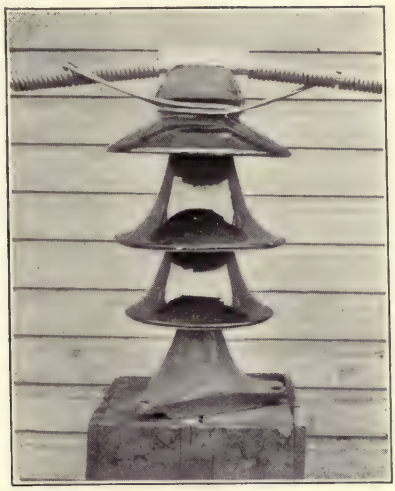


FIG. 17.—Insulator with Single Tie. 60,000-volt Insulator of the Ontario Power Co.



FIG. 18.—Insulator with Clamp. 60,000-volt Insulators of the Ontario Power Co. Upper and Lower Insulators are of Uniform Size.

device, may take the place of a regular strain insulator. An arrangement of such insulators has been installed in the transmission system of the Pennsylvania Railroad Company.[1] The insulators are placed one behind the other, each couple forming an anchor insulator and practically eliminating all danger of wires breaking at the insulators, as shown in Fig. 12. The two cross-arms provide accommodation for 18 wires, but at the present time only 10 are in use. The height of the first row of insulators from the floor of the platform is 7 feet 6 inches, and of the top row, 10 feet 6 inches. This gives an abundance of room for linemen to work with safety.

The insulators are placed longitudinally 3 feet between centers, with the exception of the third insulator from each end, which is placed 3 feet 6 inches from the second. This variation permits of symmetrical spacing with reference to the upright supports of the cross-arms. They measure $6\frac{7}{8}$ inches across the umbrella and are 6 inches high, each insulator having two petticoats. They were designed for a voltage of 25,000, but the present service pressure is only 13,000 volts.

Insulator Pins. Wooden pins have been extensively used on transmission systems up to 30,000 volts. However, in localities subject to salt storms, heavy sea fogs and near chemical manufactories, there has been more or less pin burning without regard to the type of insulator used, or the voltage of the system. It has been reported[2] that certain plants using only 440 volts, have at times great trouble from the burning of pins, although 10,000-volt insulators are used. To overcome such difficulties, pins are provided with porcelain bases. Nearly all wooden pins are made of locust, oak or eucalyptus, and are chemically treated for preservation. All standard wooden pins are 1 inch in diameter and have 4 threads per inch. A modification of the wooden pin to-day more commonly used, is an iron bolt with a wooden top which screws into the insulator, and is provided with a porcelain base. Such a pin is illustrated in Fig. 14. A still more satisfactory type for high-tension transmission is an all-steel pin as seen in Fig. 15. It is made in various modifications and used on wooden cross-arms as well as steel. Sometimes the steel pin is made in a single piece, either forged or cast, a type of which is illustrated in connection with the insulators of the Ontario Power Company (see Fig. 16).

Method of Tying Conductors. The tying of the line conductor to the insulator is done in different ways, such as the patent Clark system or as illustrated in the accompanying illustrations. Figs. 17 and 18 show the methods adopted by the Ontario Power Company. One shows aluminum tie wires; and in the other, the conductor is held in place by a clamp on a cast iron cap cemented to the insulator. These insulators are 14 inches in diameter and are designed for the 60,000-volt transmission system. They are about 27 inches high including the steel cast pin, and weigh about 80 pounds.

Section Switches. Section switches are located where duplicate lines run parallel and near each other, so that, in emergency cases, defective sections may be easily cut out and by-passed. They are also located at places where, in the near future,

[1] Steel Transmission Towers on the Jersey Meadows. *Electrical World*, Dec. 14, 1907.

[2] Burning of Wooden Pins on High Tension Transmission Lines, by C. C. Chesney. *Am. Inst. E. E.*, March, 1903.

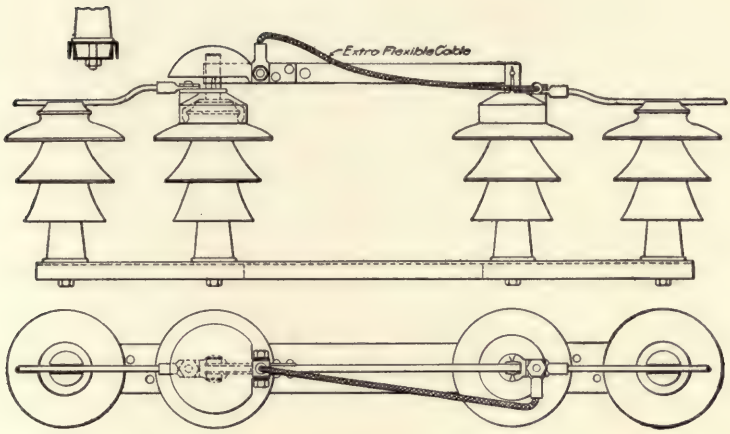


FIG. 19.—Line Disconnecting Switch.

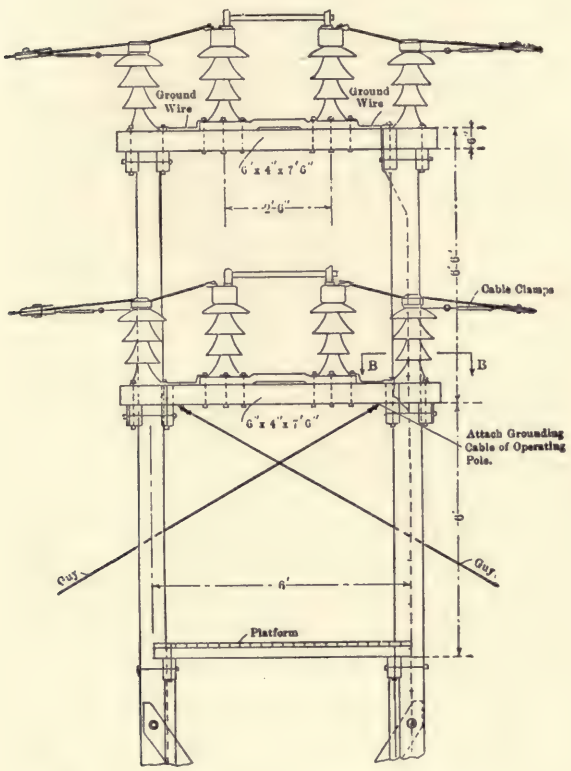


FIG. 20.—Open Air Section Switch.

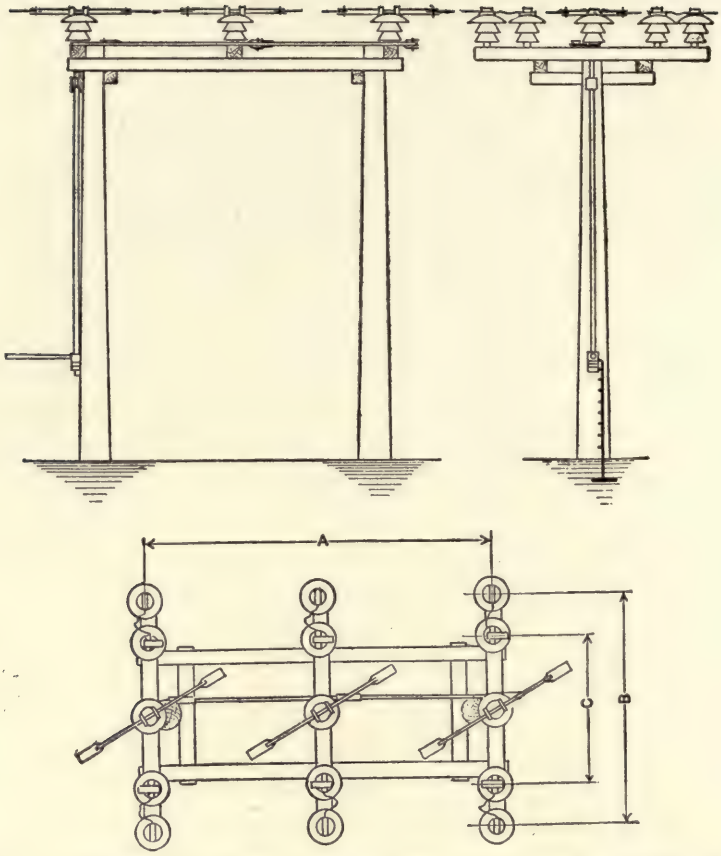
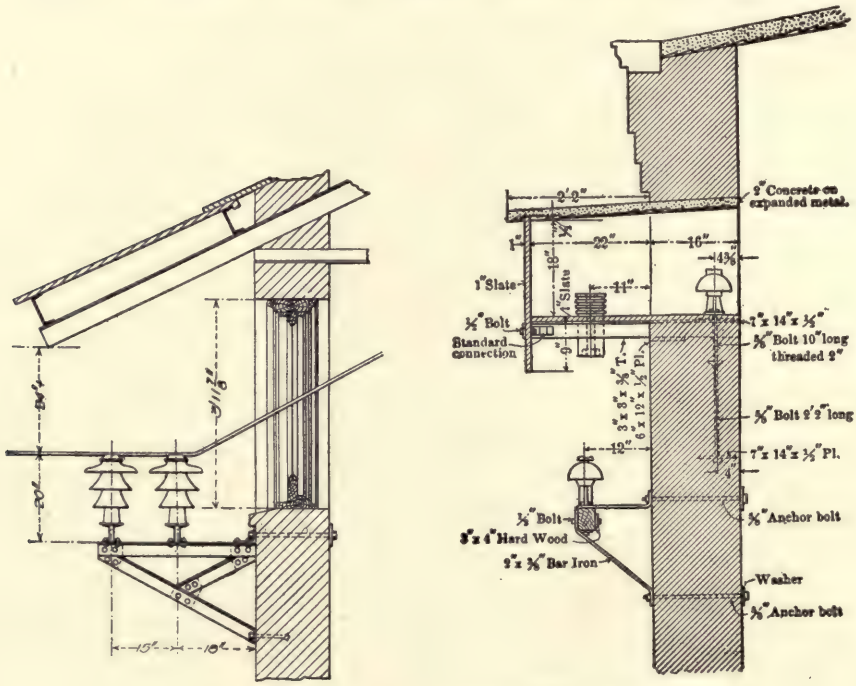
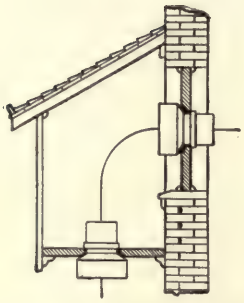


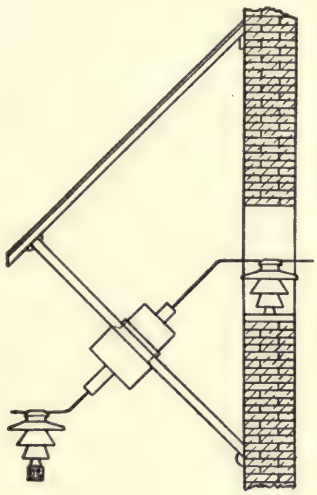
FIG. 21.—Outdoor Two Break Section Switch used on the Pacific Coast.



FIGS. 22 and 23.—Typical Wall Outlets.

taps will have to be made. The common section switch is nothing more than a disconnecting switch such as used in the generating station, but usually larger and heavier, and mounted on line insulators. They are usually placed directly in the line, similar to that shown in Fig. 20, which has been installed in a transmission system





FIGS. 24 and 25.—Typical Wall Outlets. Locke Insulator Company.

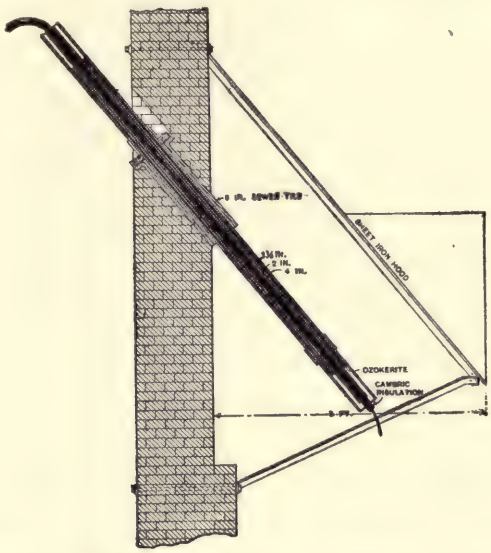


FIG. 26.—Provo, Permanent Wall Outlet. Three Concentric Tubes of Fibre Conduit.

in Auburn, N.Y. Where section houses are located in long transmission lines, the section switches are preferably placed in the houses.

Another type of section switch as used on the Pacific coast, is seen in Fig. 21. It will be noticed that the blades of the switch revolve and can be operated from the ground.

Wall Outlets. Where high-tension wires leave or enter a building, the outlet must be protected against the weather. This is accomplished in American practice, by building hoods over the wall opening as seen in some of the accompanying illustrations. Other methods are, by inserting insulating bushings in the wall. Common Continental practice is to lead the conductor through a hole of a glass panel; the hole is from one-fourth to three-eighths of an inch larger than the line conductor. Insulators are placed on both sides of the panel so that the section of the conductor going through the wall is always straight. There are no hoods or other protection provided, and it is a simple and inexpensive yet efficient arrangement.

Many Western plants and those on the Pacific coast have, for a wall outlet, a tile pipe, 18 to 24 inches, provided with a plate glass cover. Tile pipes and bushings used for wall outlets must be set on the slant, so that collected moisture can drain off outdoors.

BIBLIOGRAPHY.

HIGH TENSION POWER TRANSMISSION. 1906. A Series of Papers and Discussions at the Meetings of the A. I. E. E. under the Auspices of Committee on High Tension Power Transmission. Vol. I, 1906.

THE ELECTRICAL TRANSMISSION OF ENERGY. A. V. Abbott. 1907.

LINE CONSTANTS AND ABNORMAL VOLTAGES AND CURRENTS IN HIGH-POTENTIAL TRANSMISSIONS. E. J. Berg. *Proc. Am. Inst. E. E.*, September, 1907.

THE GROUNDED NEUTRAL, WITH AND WITHOUT SERIES RESISTANCE IN HIGH-TENSION SYSTEMS. P. M. Lincoln. *Proc. Am. Inst. E. E.*, September, 1907.

LINE CONSTRUCTION FOR OVERHEAD LIGHT AND POWER SERVICE. Paul Spencer. *Canadian Electrical News*, September, 1906.

A NEW TYPE OF INSULATOR FOR HIGH TENSION TRANSMISSION LINES. E. M. Hewlett. *Proc. Am. Inst. E. E.*, June, 1907.

SOME NEW METHODS IN HIGH-TENSION LINE CONSTRUCTION. H. W. Buck. *Proc. Am. Inst. E. E.*, June, 1907.

HIGH-TENSION INSULATORS, FROM AN ENGINEERING AND COMMERCIAL STANDPOINT. C. E. Delafield. *Electrical Review*, N.Y., Sept. 28, 1907.

THE CORONA EFFECT AND ITS INFLUENCE ON THE DESIGN OF HIGH TENSION TRANSMISSION LINES. Lamar Lyndon. *Am. Inst. E. E.*, Philadelphia Section, Nov. 9, 1909.

TRANSMISSION LINE CROSSINGS OVER RAILROADS. Ralph D. Mershon. *Railroad Gazette*, Feb. 7, 1908.

THE CENTRAL STATION DISTRIBUTING SYSTEM. H. B. Gear. *Electrical Age*, January, 1908.

AMPERES IN ALTERNATING-CURRENT CIRCUITS. A. D. Williams, Jr. *Electrical World*, Aug. 8, 1908.

GROUND DETECTORS AND THEIR CONNECTIONS. James T. Coe. *American Electrician*, December, 1905.

THE DISTRIBUTION OF PRESSURE AND CURRENT OVER ALTERNATING-CURRENT CIRCUITS. A. E. Kennely. *Harvard Engineering Journal*, November, 1905.

SIMPLE DIAGRAMS FOR THREE-PHASE POWER CALCULATIONS. Alfred Still. *Power*, March, 1906.

PRESENT STATUS OF EUROPEAN PRACTICE IN TRANSMISSION LINE WORK. *Electrical World*, Dec. 22, 1906.

SOME POWER TRANSMISSION ECONOMICS. Frank G. Baum. *Proc. Am. Inst. E. E.*, May, 1907.

HIGH-PRESSURE DIRECT CURRENT TRANSMISSION. *Electrical Review*, London, June 7, 1907.

THE TRANSMISSION OF ELECTRICAL ENERGY BY DIRECT CURRENT. J. S. Highfield. *Inst. E. E.* March 7, 1907.

POTENTIAL STRESSES AS AFFECTED BY OVERHEAD GROUNDED CONDUCTORS. R. P. Jackson. *Proc. Am. Inst. E. E.*, April, 1907.

EARTHING THE NEUTRAL, WITH AND WITHOUT SERIES RESISTANCE IN HIGH TENSION SYSTEMS. Paul M. Lincoln. *Proc. Am. Inst. E. E.*, September, 1907.

THE GROUNDED NEUTRAL. F. G. Clark. *Proc. Am. I. E. E.*, September, 1907.

RECENT PRACTICE IN ELECTRICAL TRANSMISSION OF POWER. W. B. Esson. *Engineer*, London, Dec. 14, 1906.

PRESSURE RISE ON HIGH TENSION TRANSMISSION LINES. E. Hudson. *Electrical Engineer*, London, April 26, 1907.

EXPERIMENTS WITH HIGH POTENTIALS. *Electrical World*, Jan. 26, 1907.

LINE CONSTANTS AND ABNORMAL VOLTAGES AND CURRENTS IN HIGH-POTENTIAL TRANSMISSIONS. Ernst J. Berg. *Proc. Am. Inst. E. E.*, September, 1907.

THE LOCALIZATION OF EARTH LEAKAGES ON A THREE-WIRE NETWORK. *Electrical Engineer*, London, April 12, 1907.

PROTECTIVE DEVICES FOR HIGH TENSION TRANSMISSION CIRCUITS. J. S. Peck. *Institute of Electrical Engineers*, March, 1908.

DETERMINING THE SIZES OF ALTERNATING CURRENT LINE WIRES. N. T. Carl. *Power*, July 28, 1908.

LONG DISTANCE ELECTRIC TRANSMISSION OF POWER. L. S. Bruner. *Proc. Engr's Club of Phila.*, April, 1908.

A TRANSMISSION LINE CONSIDERED AS A MECHANICAL STRUCTURE. W. T. Ryan. *Electrical World*, Feb. 29, 1908.

COMPENSATION OF PRESSURE VARIATIONS ON ALTERNATING CURRENT NETWORK SUPPLYING MOTORS. A. Heyland. *Electrician*, London, April 24, 1908.

THE TANGENTIAL SYSTEM OF SUSPENDING OVERHEAD TROLLEY AND TRANSMISSION WIRES. Robert N. Tweedy. *Electrician*, London, May 15, 1908.

SOME FEATURES OF EUROPEAN HIGH TENSION PRACTICE. Frank Koester. *Electrical Age*, December, 1908.

SOME POWER TRANSMISSION ECONOMICS. F. G. Baum. *Proc. Am. Inst. E. E.*, May, 1907.

ONE-PHASE HIGH-TENSION POWER TRANSMISSION. E. J. Young. *Proc. Am. Inst. E. E.*, May, 1907.

INDUCTIVE DISTURBANCE IN TELEPHONE LINES. Louis Cohen. *Proc. Am. Inst. E. E.*, May, 1907.

TRANSMISSION-LINE TOWERS AND ECONOMICAL SPANS. D. R. Scholes. *Proc. Am. Inst. E. E.*, May, 1907.

POTENTIAL STRESSES AS AFFECTED BY OVERHEAD GROUNDED CONDUCTORS. R. P. Jackson. *Proc. Am. Inst. E. E.*, April, 1907.

HIGH-VOLTAGE DIRECT-CURRENT AND ALTERNATING-CURRENT SYSTEMS FOR INTERURBAN RAILWAYS. W. J. Davis, Jr. *Proc. Am. Inst. E. E.*, August, 1907.

CHAPTER IX.

SUBSTATIONS.

GENERAL ARRANGEMENT.

Location of Substations. Substations or receiving stations are designed to act as distributing centers for light and power. Where a source of direct current is desired, the substation houses, rotary converters, or motor generators set.

The substations as a rule are located as near as possible to the center of gravity of their systems of distribution. This cannot always be done, as the demands on the station vary in certain sections during the different seasons, particularly in street railroad work. In many cases, to help out in the latter instance, portable substations are run to the centers of increased demand, and remain until the load on the line can be taken care of by the substation proper.

Size of Units. The size of units, may they be generators, transformers, converters or motor generator sets, depends upon the capacity of the plant and upon the load factor. Care must be taken to have one or two units in reserve, depending upon the size of the plants. American practice is to overload the units 50 per cent, while European, only 20 to 30 per cent.

Fixed rules as regards the size of the individual capacities cannot be laid down, as they all depend on the nature of loads at various times. Each case has to be individually treated, which is best done by plotting load curves for the day, week, and possibly for the month; in many instances it is necessary to plot curves for the whole year, particularly for suburban railways, and heavy lighting loads, where great fluctuations occur during certain seasons of the year.

Arrangement of Substation. In transformer substations, transformers are usually located in fireproof compartments, provided with iron rolling shutters. To facilitate inspection and repairs, a track is run in front of the compartments, so that the transformers may be readily removed on a small truck and then shifted to the repair room. Such transformers are provided with wheels and ratchet, resting on a rack. The truck is also provided with a rack so that the transformers are easily shifted to the truck without the aid of an overhead crane. Where converters are used, the transformers are not housed in compartments, but are set opposite the converter on the main floor, where they are handled by an overhead crane.

Figs. 1 and 2 show typical arrangements of transformers, switchboards, converters, etc. It will be observed that the substation of the Connecticut Railway and Lighting Company is provided with a large storage battery; for such auxiliaries separate apartments are required.

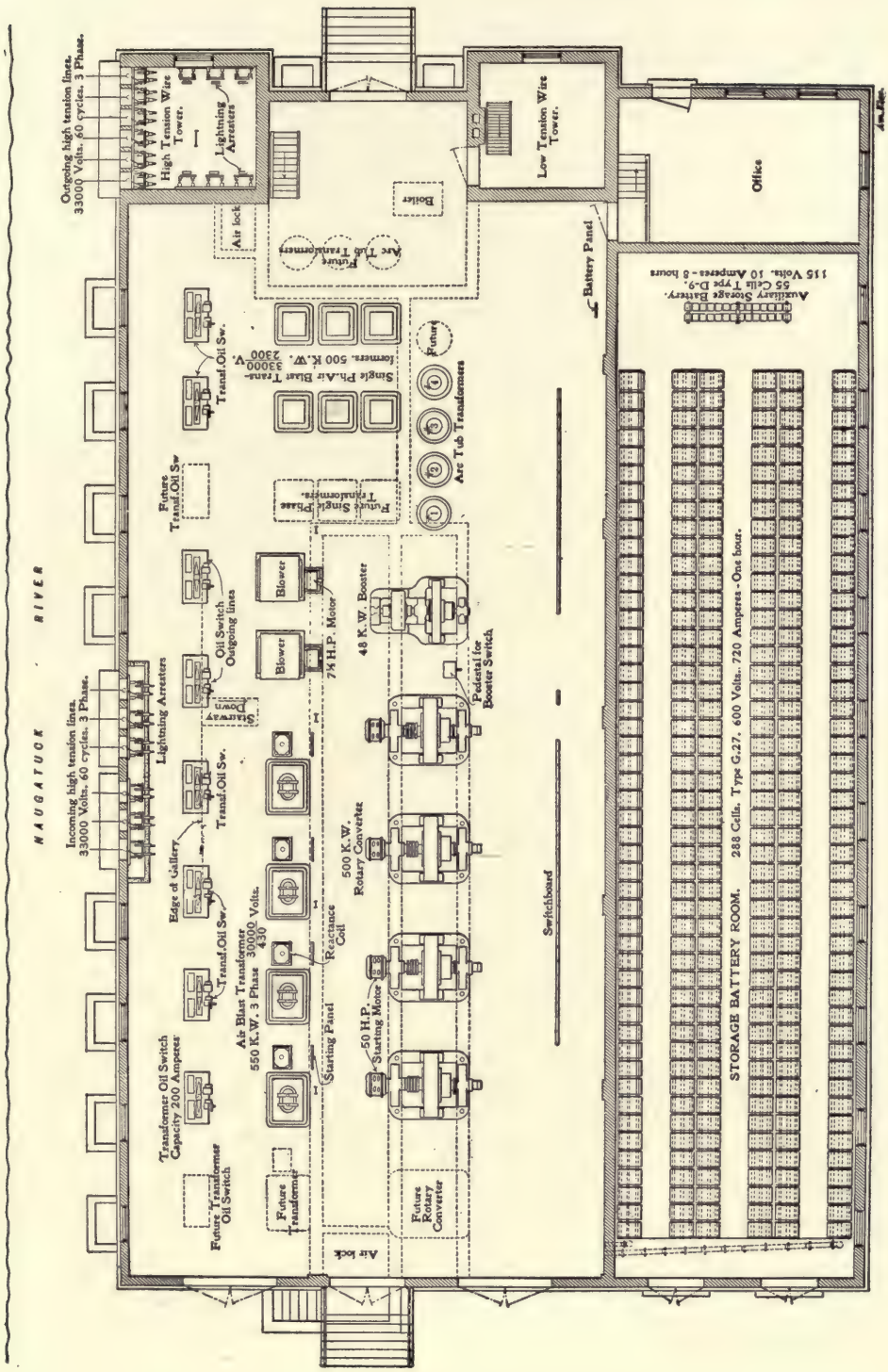


FIG. 1.—Plan of Waterbury Substation, Connecticut Railway and Lighting Company.

A very novel arrangement of a substation is that at Piattamala, Italy. The transformers are arranged in two banks each, to accommodate twelve 1250-K.W. 7000/50,000-volt single-phase, oil-cooled transformers. The current is received at one end of the building; the two sets of low-voltage busses are located on a

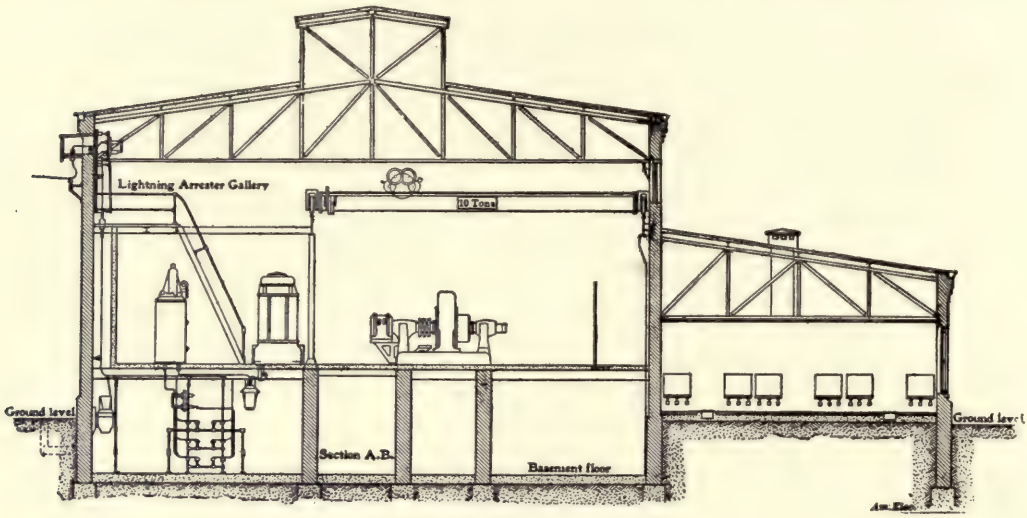


FIG. 2.—Cross Section of Waterbury Substation.

mezzanine floor above the passage between the banks of transformers. The current leaves at the other end of the building.

Ventilation. In laying out a substation, it must be borne in mind that even the normal operation of the transformers and converters will considerably increase the temperature, therefore provision must be made for good ventilation. This is particularly important where oil-cooled transformers are used. It is unnecessary to provide any auxiliary means for heating in compact substations which carry a station load factor equal to average practice, and run 24 hours per day.

Drainage. Where air-blast transformers are used, the air chambers must be waterproofed and the ducts located at such an elevation that water will not stand in the bottom. If this is not done, the transformer may be damaged by the warm air from the blowers picking up moisture and depositing it in the transformers not in service. Where any cable comes into the station, underground, the entering conduit must be sealed, and suitable drainage provided, so that water cannot leak through these openings. Where oil-cooled transformers are installed, it is good practice to provide a pit of sufficient capacity to hold the oil from several transformers, and also drainage-piping from the oil drain cocks on the transformers to the pit. These pipes must be of ample size, so that the oil can be drained off very quickly in case of emergency.

Air Compressor. An air compressor is an item which must never be overlooked in a substation as well as in a power house of any considerable size, as the life of all electrical apparatus depends to a very great extent upon cleanliness.

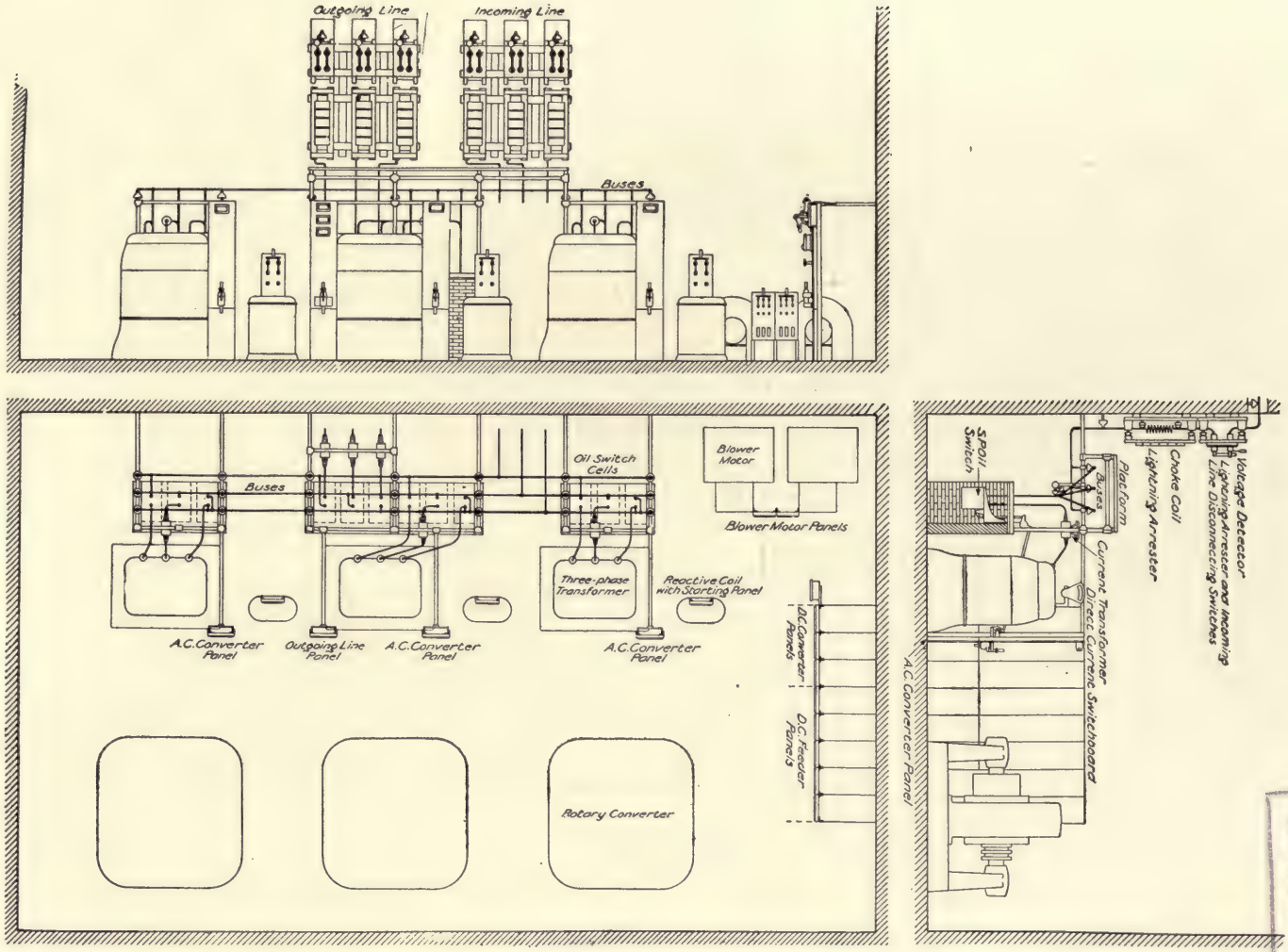


FIG. 3.—Arrangement of 13,200-volt, 3-phase Substation Equipment with Hand Operated Oil Switches.

A.E.&M.E.
UNIV. OF CAL

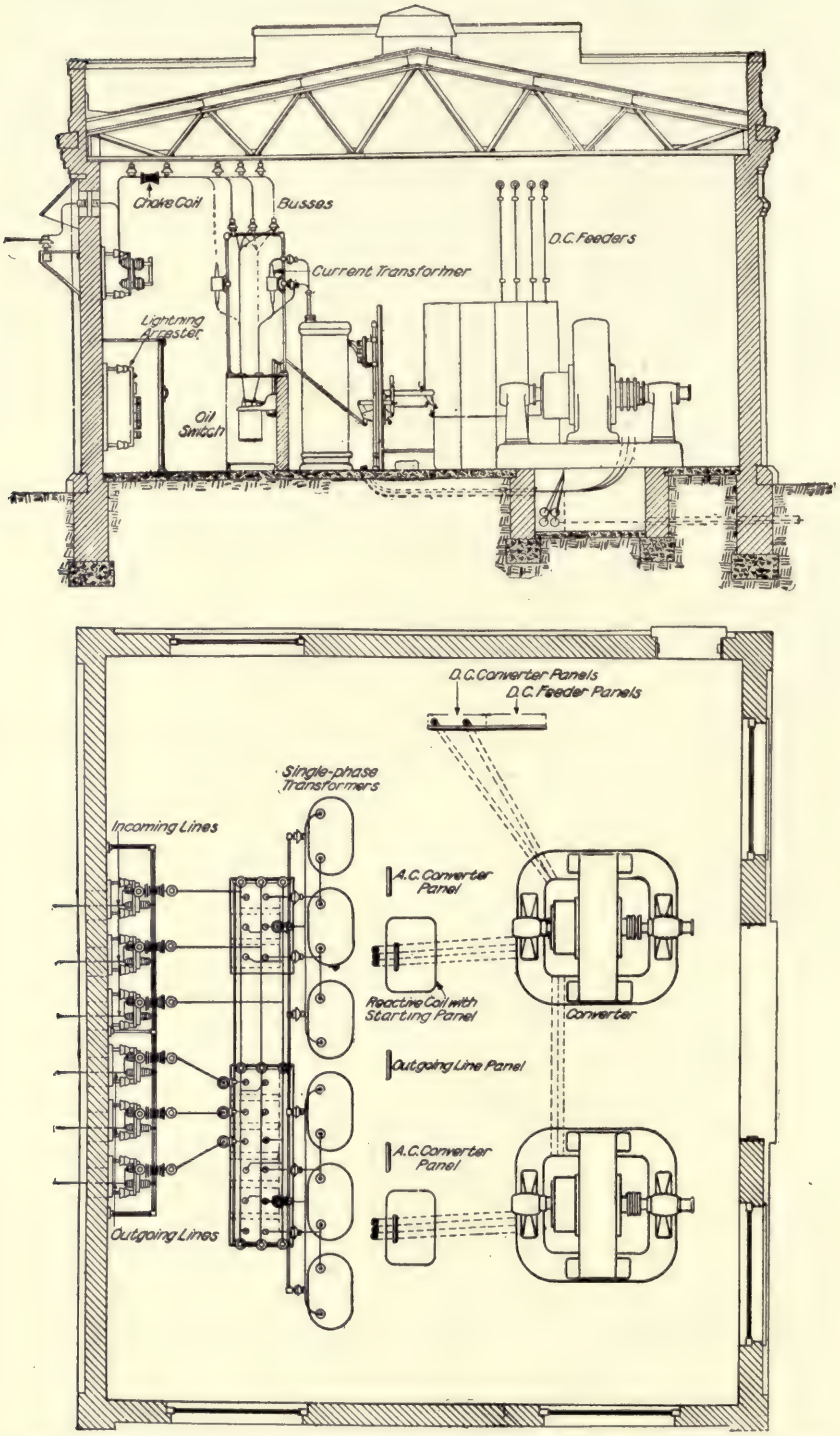
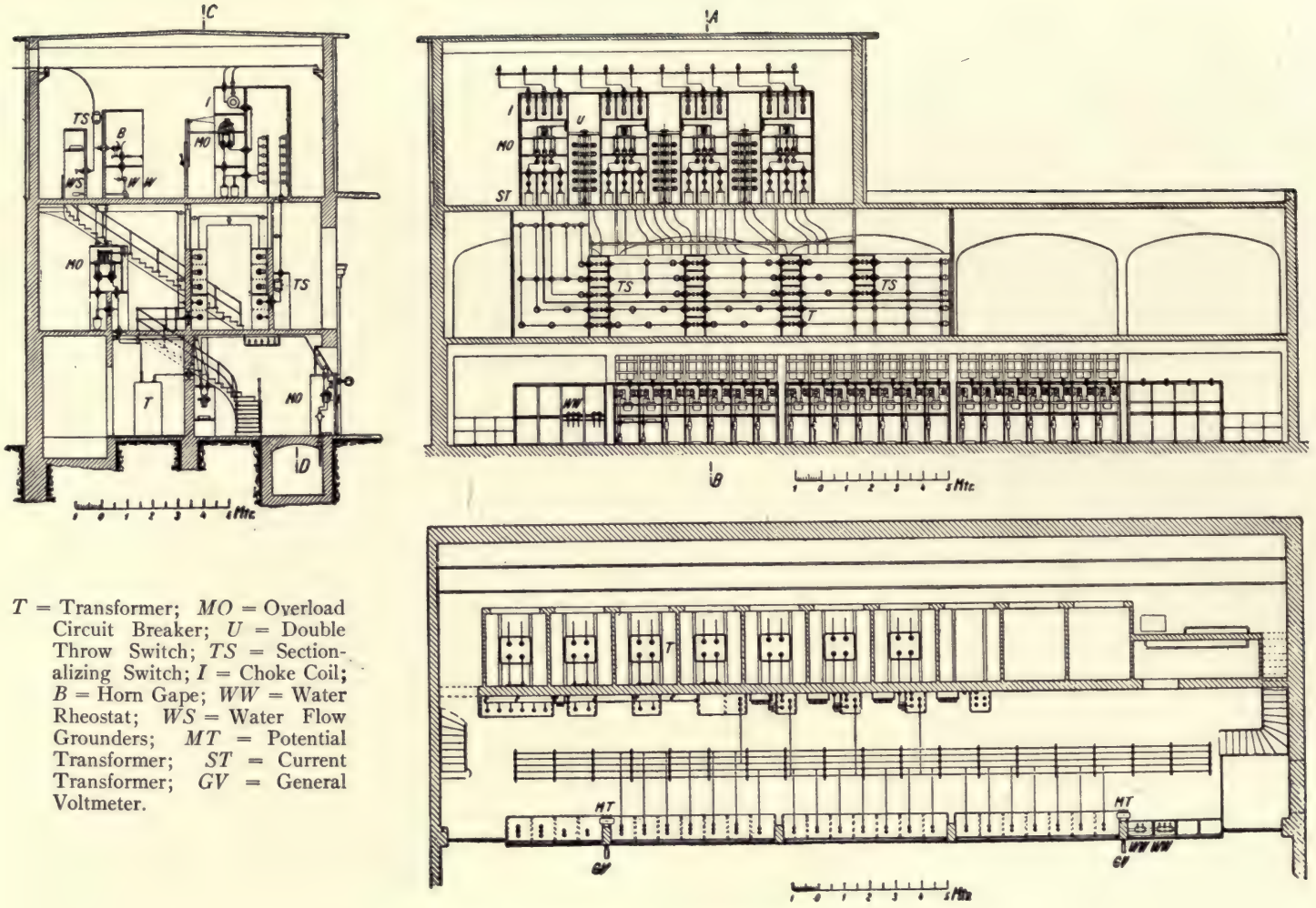


FIG. 4. — Plan and Sectional Elevation of Small Substation with Single-phase Oil-insulated Self-cooling Transformers and Hand-operated Oil Switches, 11,000 or 13,200-volt, Overhead High Tension Lines.



T = Transformer; MO = Overload Circuit Breaker; U = Double Throw Switch; TS = Sectionalizing Switch; I = Choke Coil; B = Horn Gape; WW = Water Rheostat; WS = Water Flow Grounders; MT = Potential Transformer; ST = Current Transformer; GV = General Voltmeter.

FIG. 5.—General Arrangement of Substation, Steghof, Switzerland.

Frequently, a portable motor-compressor with a small storage tank is used. Where stationary compressors are used, the air must be piped from the tank to various points in the station, where cocks must be provided for the attachment of a rubber hose. An air-pump governor is a convenient means for keeping the air in the storage tank at a constant pressure.

TRANSFORMERS.

Types of Transformers. Transformers are made either single phase or three phase, and in shell or core type. The core type is more extensively used abroad and made three phase. In America, besides the core type, the shell type is widely used, but chiefly in single-phase design.

The advantage of a three-phase transformer is its greater compactness and lighter weight, resulting in a considerable saving in first cost of transformer itself, and a saving in floor space of about 30 per cent. The connections of the transformers are simpler and fewer than in three single-phase units. The method of winding and insulating is practically the same as in single-phase transformers.

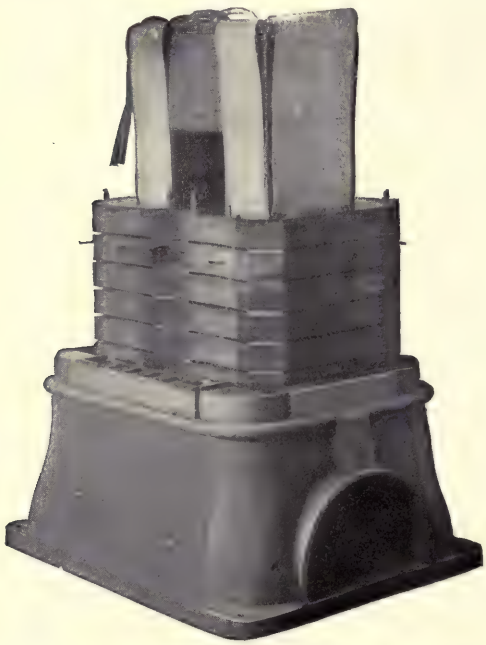


FIG. 1.—Shell Type Transformer in Process of Construction, General Electric Co.



FIG. 2.—Core Type Transformer in Process of Construction.

The difference between a shell and core-type transformer is best illustrated in Fig. 1. In the shell type, it will be noticed that the coils are almost entirely surrounded by the sheet steel laminations, and are known as "pancake" coils. To secure mechanical strength, the conductors must be rectangular in cross section

and of sufficient width. As the " pancake " coil is difficult to wind for a small transformer, the core type is preferable for small sizes.

In the core type, the core is made of sheet steel laminations and almost entirely surrounded by the winding, giving it great stability and mechanical strength, for which reason it is used for small as well as large size transformers. The coils are made of flat copper strips wound on edge. The secondary or low potential windings of these transformers are usually divided into two or more coils connected in series, on each of the vertical legs of the core.

The coils in the secondary windings of pole transformers have their leads run to a common terminal block. By interconnecting the terminals with jumpers, a limited

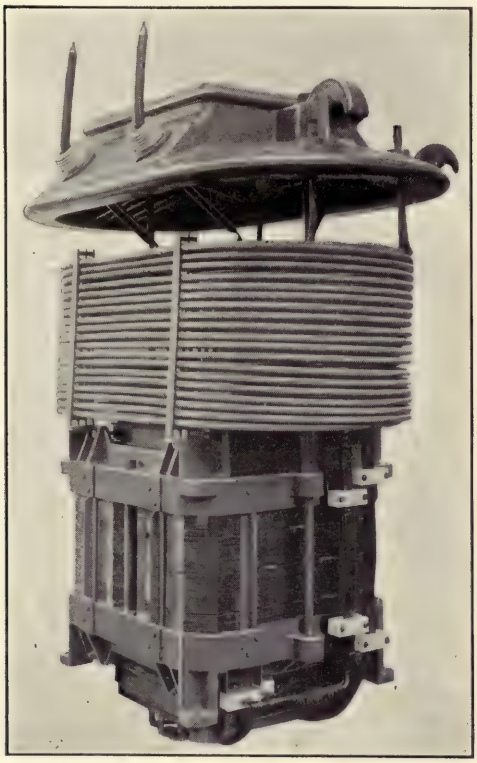


FIG. 3.—2000-K.W., 4000/60,000-volt General Electric Co.'s Shell Type Transformer.

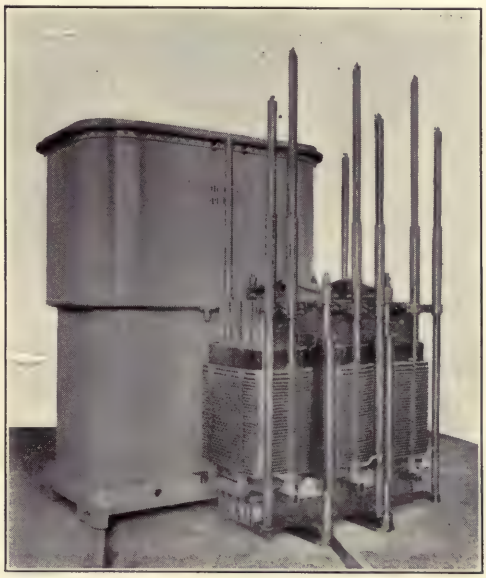


FIG. 4.—1600-K.V.A., 40,000/500-volt 3-phase Water Cooled Oil Transformer, Oerlikon Co.

range of voltages may be impressed on the service mains. The high tension windings are arranged for series or multiple connection with other transformers.

Characteristics of Transformers. Aside from the reliability and safety of operation of a transformer, the most important electrical features are the efficiency and the regulation. Although good regulation and good efficiency are always to be desired, the relative importance of the two is determined by the local conditions under which the transformer is to operate.

Where power is expensive or is used at only short intervals, the efficiency of the transformer, especially at light loads, is of great importance, but where the power is cheap, the efficiency as a rule is not so important a feature.

On account of the low cost of the power and the double transformation of the potential necessary, the important feature of transformers designed for use on high voltage circuits, is the regulation and not the efficiency, especially not the efficiency at light loads.

Regulation of Transformers. In large transformers for long-distance transmission, close regulation is of even greater importance than in the ordinary small transformer for lighting circuits, as the drop in the line is often of considerable magnitude; and

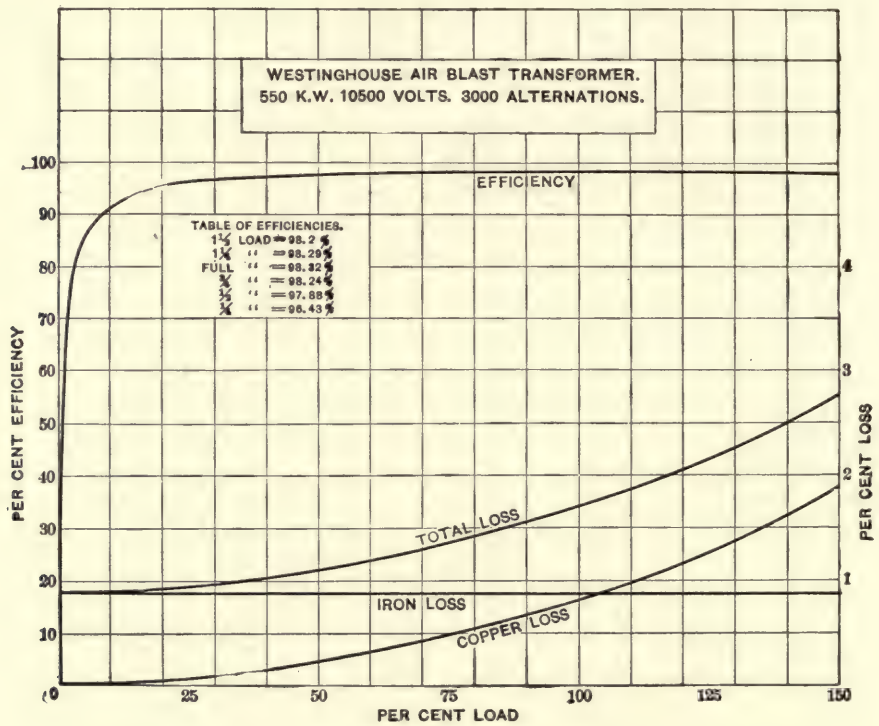


CHART I.

with raising and lowering transformers, the transformer drop occurs twice between the generator and the load. This drop is generally increased when the power factor of the load falls below unity, as is usual in power work. It is therefore particularly necessary that close regulation be obtained in the transformers designed for transmission work, especially if they are to be used for supplying inductive loads.

Transformers for such service are usually designed to have good regulation for loads of any power factor. The second set of curves, Chart I, illustrates the operating characteristics of a transformer designed for transmission work where the power factor of the circuit is low.

The regulation of a transformer depends largely upon the resistance drop, and the inductive drop within it. The former is fixed by the amount of copper loss at full load, the latter by the number of turns in the winding and the relative position of the coils and the space between them.

In a transformer designed for good regulation, it is therefore essential to have the two windings as close together as possible, a result obtainable only by using the best insulating materials to separate them, and to have low copper loss at full load.

Some stations supply a service where the transformers are connected to the supply mains continuously, and current is taken from the secondary for only a few hours during the day. In such a case, the iron losses are incessant and the copper losses intermittent. The transformer must be of such a design that the iron losses are the lowest possible, otherwise the total work received during the day will greatly exceed the work given out. The ratio of the work given out to the work received during the day is called the all-day efficiency.

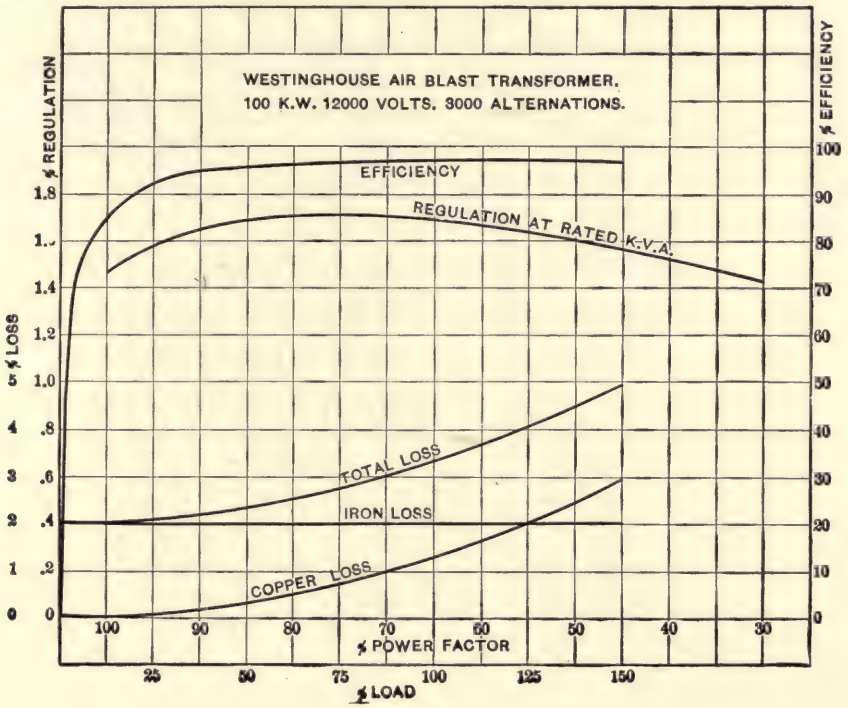


CHART II.

Efficiency of Transformers. The efficiency of transformers depends on the losses, which are of two kinds, viz., iron and copper. The former is due to magnetic reversals in the iron and practically constant for all loads. To obtain a high efficiency at small loads the iron losses must be extremely low, as will be seen in Chart II. The copper losses result from the passage of current through the conductor, and are very low for high efficiency at full load. In general, it may be stated that the efficiency of transformers is from 97 to 98.5 per cent.

Connections. Transformers are connected in a variety of ways for transmission work: single phase, 2-phase, 3-phase-delta, 3-phase-star, 3-phase-T, 3-phase-V, 2-phase-3-phase, 3-phase-star and delta. These connections give equal voltages across any leg.

For 3-phase-star or delta connections, three single-phase transformers are necessary. In the star or Y-connection, three corresponding terminals are joined in a common point. In the delta connection, the terminals must be so connected that the windings form a continuous or closed circuit; like terminals must not be connected; this causes bucking.

The Scott method of connecting two transformers of equal capacity affords a very convenient means for obtaining a 2-phase-3-phase transformation, or vice versa. It is seldom used for long-distance transmission work.

The high and low tension windings of both transformers have taps brought out from the middle and 86 per cent points. By connecting the 86 per cent point of one to the mid point of the corresponding winding of the other, the transformers will give a 2 or 3-phase conversion with voltage transformation, according to the phase of the supply mains.

On low tension, supply and service 2-phase lines, where two transformers are used, the system can be reduced from a four to a three-wire by connecting the two transformers in series; one line to each of the free terminals, and the third to the junction of the two.

The choice of connections affects the design of the transformers to be employed. With Y-connections, each transformer is wound for only 58 per cent of the line potential, and for full line current. On the other hand, Δ-connections require windings for full line potential, and only 58 per cent of the line current. From this, the Y-connection requires only 58 per cent of the windings needed in a delta connection, with the conductor cross section correspondingly greater.

It is readily seen that more windings with their insulation necessitates larger and more expensive coils; this, in turn, calls for a longer magnetic circuit, consequently a large and heavy transformer.

Where the transformer current is heavy, a conductor of large cross section is necessary. To accomplish the same end, the windings are split into multiple circuits of small cross section, and can be easily handled.

Trouble with one transformer in a Y-connection renders the bank inoperative. Any one of the transformers in a delta group may be cut out, and the remainder will still deliver 3-phase power up to two-thirds capacity of the entire bank.

As a rule, most Y-connected systems have the common or neutral point grounded. Occasionally, the neutral point, instead of being grounded, is connected to a main, thus making a 4-wire 3-phase system possible. The voltage between this and any of the mains is 58 per cent of that between any of the phases. This practice is confined to low-tension service distribution.

Delta vs. Y-Connections. Delta-connected transformer primaries have been customarily used, to permit operation with two transformers in case of trouble with the third. It has not been usually appreciated, that with the primary windings

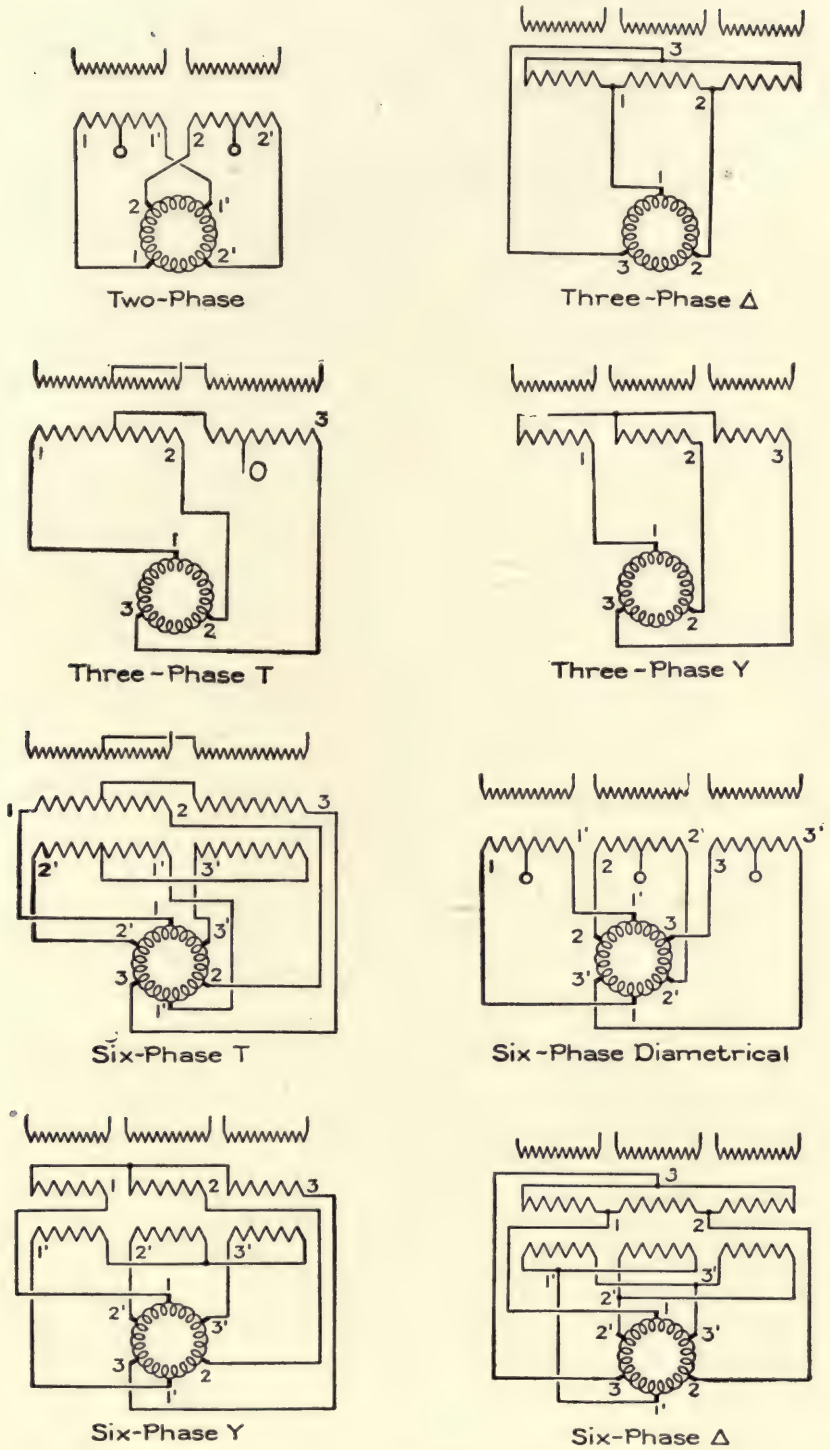


FIG. 5.—Method of connecting Transformers to Rotary Converters.

Y-connected with the neutral solidly grounded, and with the high-tension neutral of the generating system also grounded, three-phase or six-phase converters may be started and successfully operated with two transformers per converter, in case of trouble with the third.[1]

The output in either of the above emergency cases is, of course, limited to that of the transformers in use. With the grounded Y-connections, the service may be maintained in case of trouble on one phase of the transmission line, the other two wires and ground serving as the circuit.

Should three-phase shell-type transformers be installed with high-tension delta or grounded Y-connections, two phases may be likewise operated, provided both windings of the third phase are disconnected and short-circuited. The output of the unit is limited in this case, to the capacity of the two transformers or phases, instead of the three.

Transformers for higher pressures than 20,000 volts must be used Y-connected with primary neutral grounded, but may be operated delta at 0.57 times their rated Y-voltage, if initially lower voltages are wanted than those for which they are designed.

Oil-Cooled Transformers. The oil-cooled transformer is the most extensively used, for the reason that oil is a better heat-conducting medium than air; besides, oil preserves the insulation, keeping it soft and pliable, and prevents oxidization by air;

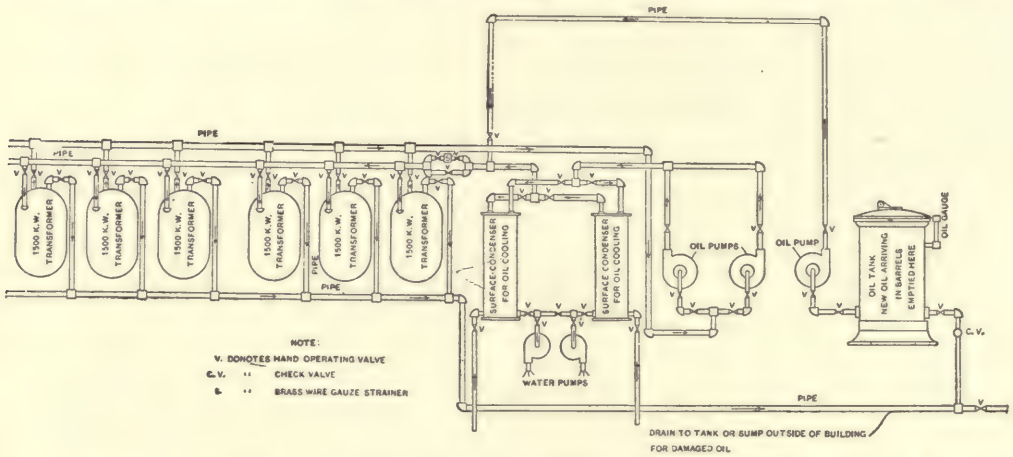


FIG. 6.—Forced Oil Circulation for cooling Oil-Insulated Transformers.

consequently the use of oil maintains a uniform core loss and a superior insulation. The oil in the transformer is cooled, either by its natural gravity circulation or by means of submerged coils through which water is circulated.

The amount of water necessary for cooling the oil depends on the temperature of the incoming and outgoing water. Theoretically, each kilowatt loss will give up 57 B.t.u. per minute, or, in other words, 57 pounds of water are raised 1° F. In practice, however, the amount of water required varies with the design, and the amount of water necessary can be obtained from the manufacturer.

[1] See paper, Y or Δ Connections of Transformers, by F. O. Blackwell, presented at 20th Annual Convention Am. Inst. E. E., Niagara Falls, N.Y., July 1, 1903.

Another design of transformer, instead of using water coils, the upper part of the transformer is provided with submerged radiating ribs cooled by circulating water. Transformers of this design, having a capacity of 1250 K.V.A., 7700/50,000 volts, have been installed at the Italian substation at Piattamala.

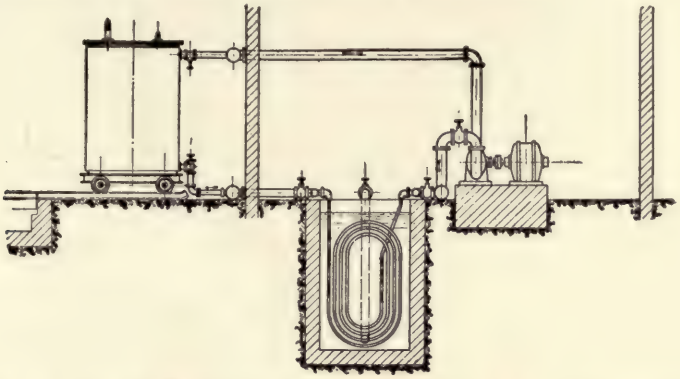


FIG. 7.—Method of Cooling Circulating Water for 6750-K.V.A. 6600/66,000-volt 3-Phase Siemens-Schuckert Transformer, Molinar Plant, Spain.

In order to keep the temperature rise of this transformer below 45° C., 5 gallons of water per minute at a temperature of 15° C. are required. For a 25 per cent overload for 6 hours, 10 gallons are required; for 2 hours at same overload and using 5 gallons, the permissible temperature rise is 60° C.

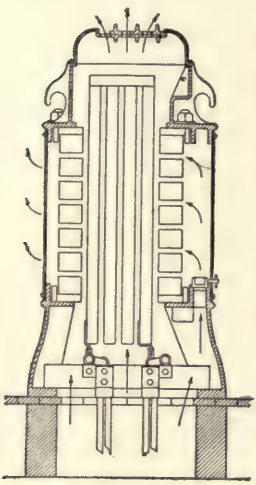


FIG. 8.—Air-Cooled Transformer

Forced Oil-Cooled Transformer. Another method of cooling the transformer oil, is by forced circulation, and has the advantage of doing away with the cooling coils. Instead of the oil being cooled in the transformer, it is cooled outside in a cooling device which works on the same principle as a cooling pond or a surface condenser.

A very elaborate system of this kind is given in Fig. 6.[1] It will be observed that besides water pumps, a set of oil pumps is necessary, while with the water-cooled system, only water pumps were required. Where sufficient head is obtainable, the water-pumps may, of course, be eliminated.

With a forced-oil circulation, the transformers are small and less expensive, due to the elimination of cooling coils; however, an extra cooling system is necessary, the cost of which in small plants will outstrip the reduced cost in transformers. In transformer plants over 4000 K.W., the forced-oil system seems preferable.

Air-Cooled Transformers. In the early type of transformers, the cooling was done by natural air-draft, or forced draft. The latter is still very much in use. The cores

[1] Forced-Oil and Forced-Water Circulation for Cooling Oil Insulated Transformers, by C. C. Chesney. *Am. Inst. E. E.*, April, 1907.

of the transformer are incased, through which air is forced by means of a blower. Where there are a number of transformers, they are preferably set over a common duct and supplied with air from a blower at either end, one being kept in reserve. They are most conveniently operated by motors. The volume of air required for air-blast transformers depends on the outside temperature, as well as the entering and

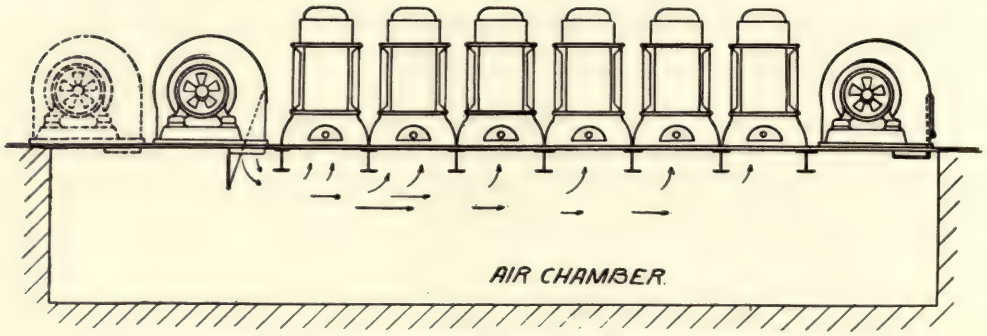


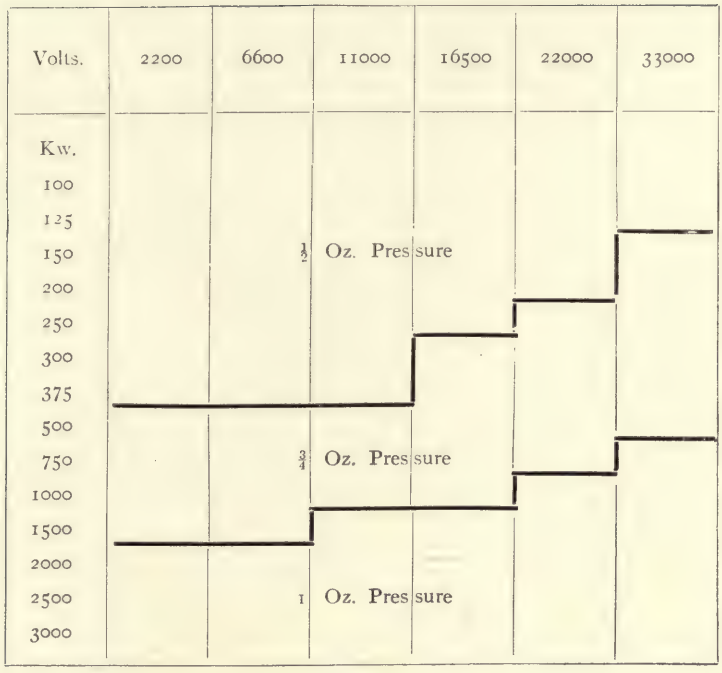
FIG. 9.—Arrangement of Air Blast Transformers.

discharge temperature, and to great extent on the design. Under normal load and continuous operation, the temperature rise must not exceed 35 to 40° C; at 25 per cent overload, 50° C.; at 50 per cent overload, 60° C. The temperature rise is taken by thermometers or calculated from the increase in resistance. The pressure furnished by the blowers depends on their size and the length of the ducts. High-voltage transformers usually require higher air pressure. Fig. 10 gives approximately the air pressure required for different capacity transformers. A more complete table on this subject is found in Table I.

TABLE I. — AIR REQUIRED FOR TRANSFORMERS.

Total kilowatt trans.	Size of units kilowatt.	Cubic feet air required per transformer per minute.	Cubic feet air required for all transformers per min.	Cubic feet air furnished by standard blower set.	Oz. Press.	Freq. Mot'r .	Size blower, inches.	Speed blower.	Horse-power to drive blower full vol. and pressure.
900	100	450	4,050	6,000	½	25 40 60	50 50 40	750 800 900	2.5
1800	200	900	8,100	8,000	⅝	25 40 60	55 55 50	750 800 900	4
2700	300	1125	10,125	10,000	⅝	25 40 60	55 55 55	750 800 720	5
4500	500	1625	14,625	14,000	⅝	25 40 60	75 70 70	500 600 720	5.5
6750	750	1875	16,875	20,000	¾	25 40 60	90 80 80	500 600 600	12
7500	1250	2800	16,800	20,000	¾	25 40 60	90 80 80	500 600 600	12

60 CYCLES.



25 CYCLE TABLE.

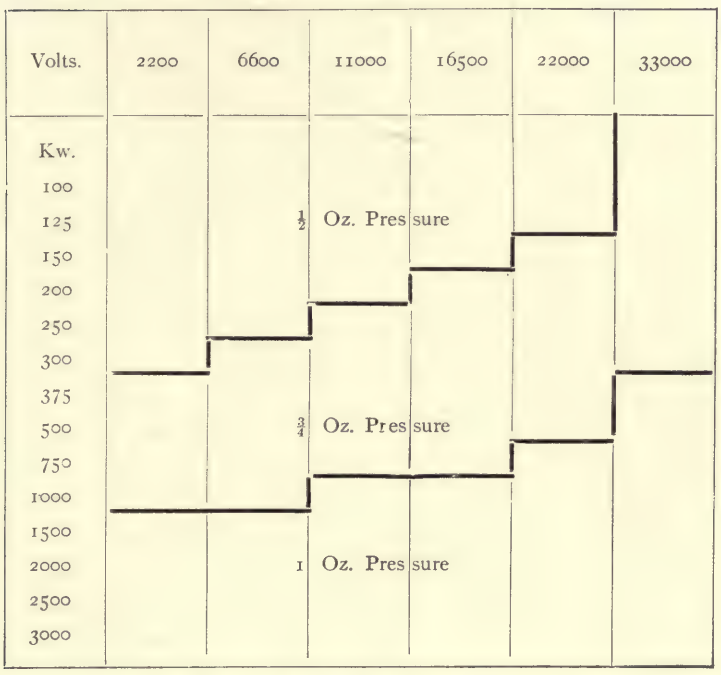


FIG. 10.—Air Required for Transformers.

With air-cooled transformers, more or less dirt is carried along with the air, and deposited along the various air passages. Much of the dirt may be obviated by keeping the air passages to and from the transformer closed when not in use. A frequent cleaning of the transformer windings with a blast of compressed air will improve conditions, and at the same time remove a possible fire risk.

Oil-insulated transformers should have the oil drained off once in a while, and all evidences of sediment removed. The emergency drains must be cleaned out at the same time.

In a recent Italian plant at Lomazzo, 1250-K.V.A., 42,000/11,000-volt transformers without casing, are placed in masonry compartments, through which the air is forced from ducts beneath. Each compartment, reaching to the ceiling, is provided with a ventilator. The reason given, is, that ready inspection can be made without removing the core, although provision is made for doing so in case of extensive repairs.

The guaranteed and test efficiencies of these transformers is as follows:

Regulation at $\cos\phi = 1.00$ full load	1 per cent
Regulation at $\cos\phi = 0.80$ full load	3 per cent
Regulation at short circuit	3 per cent
Efficiency full load	97 per cent
Efficiency half load	9.65 per cent

The operation of the blowers is included in the above-named efficiencies.

CONVERTERS.

Rotary converters are installed for transforming alternating current into direct current; however, they may be otherwise used. They may be supplied with direct current and deliver alternating. They may be connected to alternating mains and operate as simple synchronous motors, or connected to direct current mains and operated as simple direct current motors. There are a number of other electrical and mechanical connections which can be applied, but the main purpose is to serve as a means of conversion from alternating to direct current.

In general appearance and construction, the rotary converter resembles a direct current generator to which a set of collecting rings has been added. The field is composed of a cast iron yoke with inwardly projecting poles of laminated steel. It may be either shunt or compound wound. The armature consists of a slotted, laminated core with embedded coils, with the addition of taps or leads to the collector rings.

The method of cross-connecting the armature windings, which has been a means of securing superior performance in direct current generators, is applied to rotary converters with equal success. This is an effective way of preventing sparking at the commutator, as it insures uniform field strength under all the poles.

Voltage and Frequency. The ratio between the voltages at the alternating and direct current ends of a given rotary converter, is approximately constant, and cannot

be changed by altering the speed or by using a rheostat. Therefore, any alteration in one voltage will proportionately alter the other, and vice versa. In most rotary converters, the voltage on the collector rings of a two-phase machine is about seven-tenths of that at the commutator, and the voltage on the collector rings of a three-phase rotary converter is about six-tenths of that on the commutator.

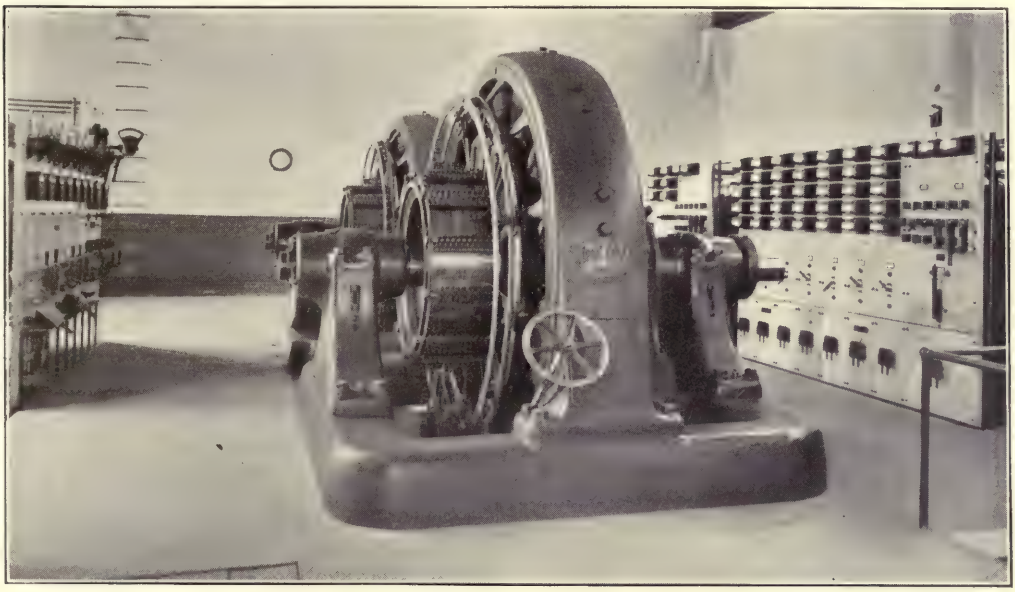


FIG. 1.—Rotary Converters in Sub-Station " d," Albina, Portland Railway Light and Power Company.

Thus, a two-phase converter receiving alternating current at approximately 385 volts will deliver direct current at 550 volts, and a three-phase converter receiving alternating current at approximately 330 volts alternating current will deliver at 550 volts direct current.

In installations supplying three-wire lighting systems, or where it is necessary to obtain two voltages, for the operation of variable speed, direct current motors, a special neutral-wire connection is required for use in conjunction with the positive and negative leads on the direct current side of the rotary. If a conductor be connected to the middle points of the secondary windings of the transformers, which supply the alternating current for a two-phase rotary, it will be found that the E.M.F. between this conductor and either of the direct current terminals is equal to one-half of the E.M.F. between those terminals. In this way 110 volts can be secured from a 220-volt machine. A similar arrangement for three-phase rotaries is secured by employing the interconnected star system of connections for the secondary winding of the transformers, the neutral lead being connected at the common junction point of the secondary windings.

The same relation exists between speed, number of poles and frequency that is

found in alternating current generators. The product of the number of poles by the speed, in revolutions per minute, is equal to the number of alternations per minute.

Rotary converters can be had for any frequency up to 60 cycles per second. The standard frequencies are 25 and 60 cycles, the former being generally used for railway service, and the latter when a combined railway and lighting service is operated, or where power is obtained from existing 60-cycle transmission plants.

Phases. The alternating current may be applied to the collector rings of the rotary converter in the form of either single, two, three or six phase currents. However, single-phase currents are seldom used, and the majority of machines are wound for either three or six phases. It is now general practice to wind 25 cycle units for railway work for three phases when under 500 K.W. capacity, and for six phases when of 500 K.W. or above. In 60-cycle machines, those under 300 K.W. are wound three-phase, and 300 K.W. and above, six-phase. Six-phase winding in the larger machines is highly desirable, because it reduces the heating, and increases the efficiency and stability of operation.

Field Connections. For highly fluctuating loads, such as those on interurban or small city railway systems, rotary converters with compound-wound fields are preferable. The compounding of such machines differs from that of direct current generators; the direct current voltage is dependent upon the alternating current voltage, and is therefore affected by the line drop, generator voltage, etc. The standard compound winding is designed to give 600 volts at both no load and full load, that is, a flat compounding, with 5 per cent drop between the generating station and the rotary converter substation. This flat compounding is obtained with the assistance of reactive coils connected between the stepdown transformers and the rotary converter. The compound-wound field coils are of the ventilated type, that is, the winding is in two layers separated by a space through which air is blown by the centrifugal action of the armature, thus greatly increasing the radiating surface of the field spools and reducing the temperature rise.

The utility of reactance will readily be understood when it is borne in mind that a rotary converter is simply a transforming device, and the ratio of the alternating voltage impressed to the direct voltage delivered, is approximately a fixed quantity and independent of the field strength. Therefore, any increase in the direct current voltage, or overcompounding, must be secured by a proportional increase of pressure at the collector rings, and it is the presence of a reactance in circuit which brings about this desired result. Or, in other words, by inserting this reactance, the line itself has been compounded, and thus made self-regulating.

In order to make use of single-pole switchboards and to do away with pedestals, each compound-wound rotary converter is fitted with a panel mounted on the machine frame, and carries the equalizer switch, as well as a switch used in connection with the shunt provided for the adjustment of the series winding.

In order to make the rotary converter panels of the switchboard of the same polarity as the direct current feeder panels (positive or trolley polarity), the series fields are connected on the negative or ground side of the circuit between the armature and the rail returns; this makes all switches on the machine frame panel of the negative

or ground potential. A double-throw field break-up switch is also included in the machine equipment, by means of which the polarity of the machine may be reversed if necessary, in starting.

Where the load is practically constant, such as in heavy services, shunt-wound rotary converters are more generally used. In such cases, the fluctuations of the load are so low that they can be followed by hand control of the field rheostats.

Starting of Converters. There are different ways to throw converters on the line starting from rest. One way is to supply the converter with a separate starting motor or one mounted on the shaft, which brings the machine up to the desired speed, and with the application of an automatic synchronizer, the converter is thrown on the line at the first instant of synchronism, and the starting motor cut off. Another method is by supplying alternating current directly to the slip rings, and is impressed upon the windings at a lower voltage than is used after the machine is run up to speed, and is in synchronism with the source of supply. This low-voltage alternating current is obtained from the stepdown transformer by means of switches, which connect the armature to low-voltage taps on the transformers at starting, and establish the connections to the full-voltage taps when the machine has reached synchronous speed.

The most common method used in street railroad work, is to start the converter as a direct current motor, supplied with current from the trolley mains. By adjusting the strength of the field windings, synchronous speed is reached and the machine thrown on the line. This method does not require any special starting apparatus, such as starting motors, or transformers with special taps. Its disadvantage lies in the fact that it is dependent on the direct current supply of the system.

Hunting. Rotary converters, to give the best service, must run in exact synchronism with the supply current, but it frequently occurs that the speed of the generator is not exactly uniform; and in such cases, the rotary will tend to follow the fluctuations of the generator speed, resulting in a surging action of the rotary armature, alternately above and below synchronism. This is commonly known as "hunting," and often assumes disastrous proportions where no provisions are made for counteracting this effect. Since hunting is an oscillation in the relative positions of the converter — ahead of the generator at one instant and behind the next — the corrective currents in the circuit due to the oscillations are first in one direction and then in the opposite. The effect of this varying current is to strengthen the leading pole tip when flowing in one direction and to strengthen the lagging pole tip when flowing in the other direction, thus constantly changing the distribution of magnetism over the pole face, and, in effect, causing the magnetic flux to continually shift back and forth across the pole face.

The fact that hunting is always accompanied by a shifting field makes possible an effective method of reducing it. Most rotaries are provided with heavy copper grids, that surround each pole face and extend across it, embedded in one or more slots. The function of the copper grids is to act as dampers, preventing the relative position of the converter armature being changed, by the corrective currents, more than the initial change in the generator. The action is essentially a damping one,

and is the same as that of the copper magnet damper used in galvanometers, and is analogous to the action of a dashpot on an engine governor.

To consider the action of the damper in detail, assume that the generator speed momentarily increases. This causes a difference in phase of the generator and converter E.M.F.'s. The difference in the instantaneous E.M.F.'s due to the difference in phase will cause a corrective current to flow in the circuit, that will

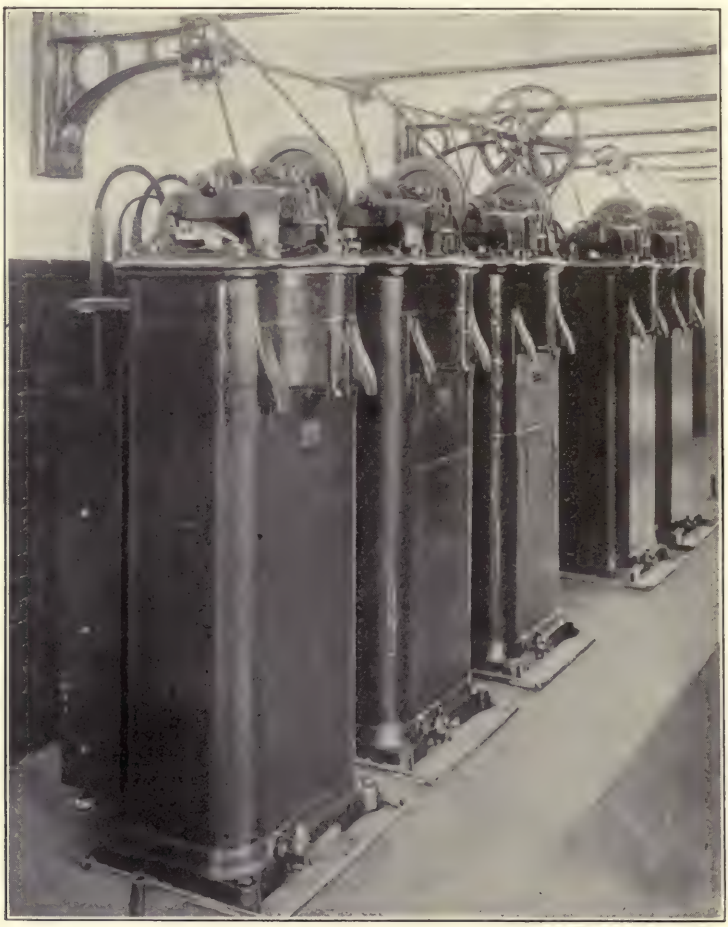


FIG. 2.—Automatic Regulators.

distort the field and accelerate the converter armature. The shifting flux cuts the copper grid and generates in it eddy currents, which retard the converter armature. The retarding action of the eddy currents occurs only while the relative positions of the converter and generator armatures are changing, i.e., while the magnetic flux is moving across the pole face. The eddy currents, therefore, do not act as a constant opposing force to the corrective currents, but as a true damping force, becoming zero whenever the generator and converter armatures revolve exactly in synchronism.

Induction Regulator. The induction regulator consists of a polyphase transformer with primary movable with respect to the secondary. The construction of core and winding resembles that of an induction motor. The primary is connected across and the secondary in series with the line. By shifting the position of the primary winding of the regulator, the secondary voltage delivered to the alternating side of the converter may be raised or lowered without opening any part of the circuit, and the voltage on the direct current side thus varied. When of sufficient size, the regulator may be operated by a small motor. This method of regulation may be employed to overcome small and infrequent fluctuations in the line voltage in lighting, electrolytic and similar service.

Compounding. It is generally understood that there is a certain adjustment of field strength which gives a minimum alternating input for a given direct current output, and that an overexcited field sets up a leading current in the line, while an underexcited field causes the line current to lag. As change in the field strength alone cannot appreciably affect the direct current voltage, the ratio between the two E.M.F.'s remaining practically fixed, the only way to vary the direct potential is to vary the alternating potential at the collector rings. It is, however, possible by a proper proportion of series excitation and the provision of sufficient inductance in the supply line, to produce a change in the voltage at the collector rings, resulting in a corresponding effect at the direct current terminals. The conditions for rotary converter compounding are, therefore, a series winding on the field connected to assist the shunt, and inductance in the line between the generator and converter. The series winding of a rotary converter does not directly increase the direct current voltage, as in a direct current generator, but acts indirectly with the aid of inductance in the supply circuit.

Rotary converters which are compounded to give a constant or increasing voltage with increasing load, maintain a practically uniform voltage at the generator terminals, and therefore do not produce the drop in voltage which usually occurs when the generator load increases. This enables a practically constant voltage to be maintained on other circuits supplied by the same generator, independent of the variations in load upon the rotary converter. Both lighting and railway loads may thus be supplied simultaneously from the same bus bars, provided the proper compensation is effected, and the fluctuations in load do not cause an appreciable variation in the speed of the generators.

In some systems, alternating current is supplied to rotary converters at a distance from the power house, while other converters, located in the power house, are supplied with current from the same generators. If the converters in the power house are to be compounded to give a rising voltage with increase of load, it is necessary to provide self-induction either in transformers or in choke coils, placed between the bus bars and the converter.

Reactances. To enable the direct current voltage to be altered by the field rheostat or automatically by compounding, which calls for a corresponding change of the alternating current voltage, a phase reactance-coil is provided between the low-tension windings of the transformer and the converter. Without such a reactance, the

maintenance of the same voltage at full load as at no load, involves excessive leading and lagging currents, and consequently excessive heating in the converter armature, unless the resistance drop from the source of constant potential is small, or the natural reactance of the circuit is unusually high. If the armature field is weakened, a lagging current is set up, which causes a drop in the reactive coil. If the field is strengthened, a leading current is set up which gives a rise of voltage in the reactive coil. Under heavy load, the series field of a compound converter tends to produce leading currents, which tendency is practically balanced by the reactance, improving the power factor of transformers, lines and generators when loaded.

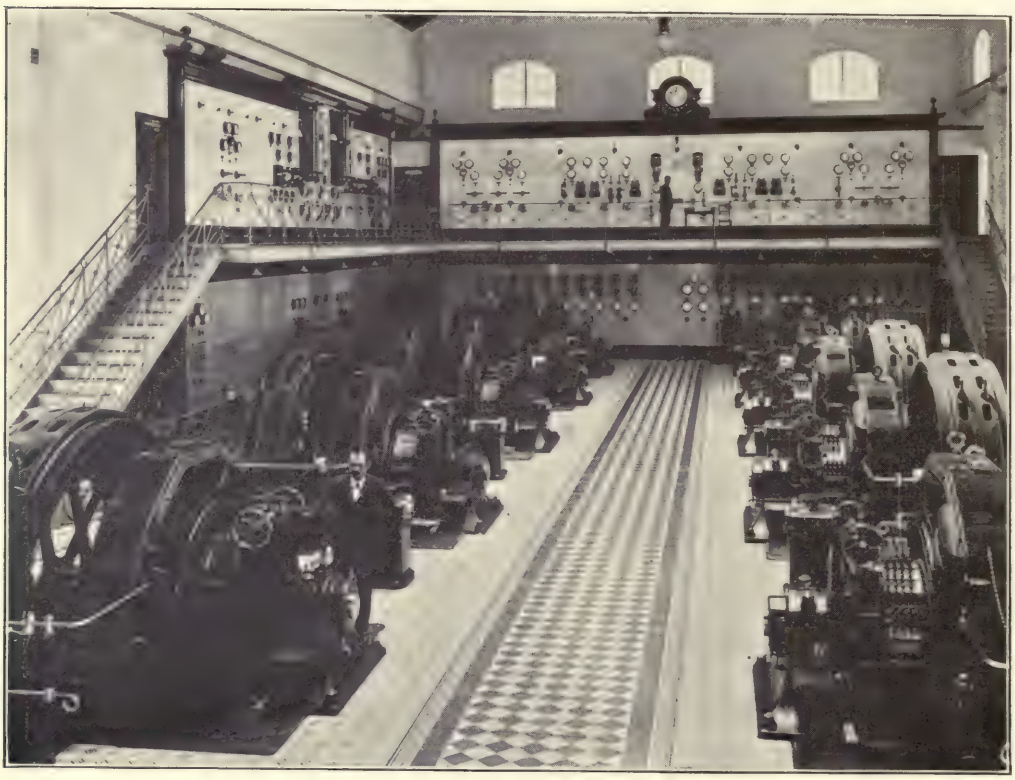


FIG. 3.—Typical Continental Motor Generator Substation. Vienna Railway System.

Motor Generators. Motor generator sets may be used in place of rotary converters, if the line voltage is not too high; the motor of the set may be directly connected to the line, thus eliminating transformers. The advantages of using a motor generator are, that no synchronizing apparatus is necessary, the voltage of the generator bears no relation to that of the supply, same as in a converter, and it may be adjusted through a wide variation. The disturbance known as "hunting" is unknown in the motor generator, when an induction motor is used as the driver, and no skilled attendants are necessary. The disadvantages are, that the efficiency is from 4 to 7 per cent less than that of a transformer-converter set, and they cost

more. With what voltage a motor generator can be used without the use of a step-down transformer, depends entirely upon the design of the motor. The accompanying illustrations give an idea of motor generator sets as used in Europe where they are most extensively employed. Fig. 4 shows the interior of a substation at Steghof, Switzerland; each motor generator consists of a 340-K.W., 2650-volt, alternating current motor, coupled to a 300-K.W., 575-volt, direct current generator, running at 490 R.P.M.

Frequency Changers. A frequency changer differs from a motor-generator set in the following respects: The driving motor must be a synchronous motor and the

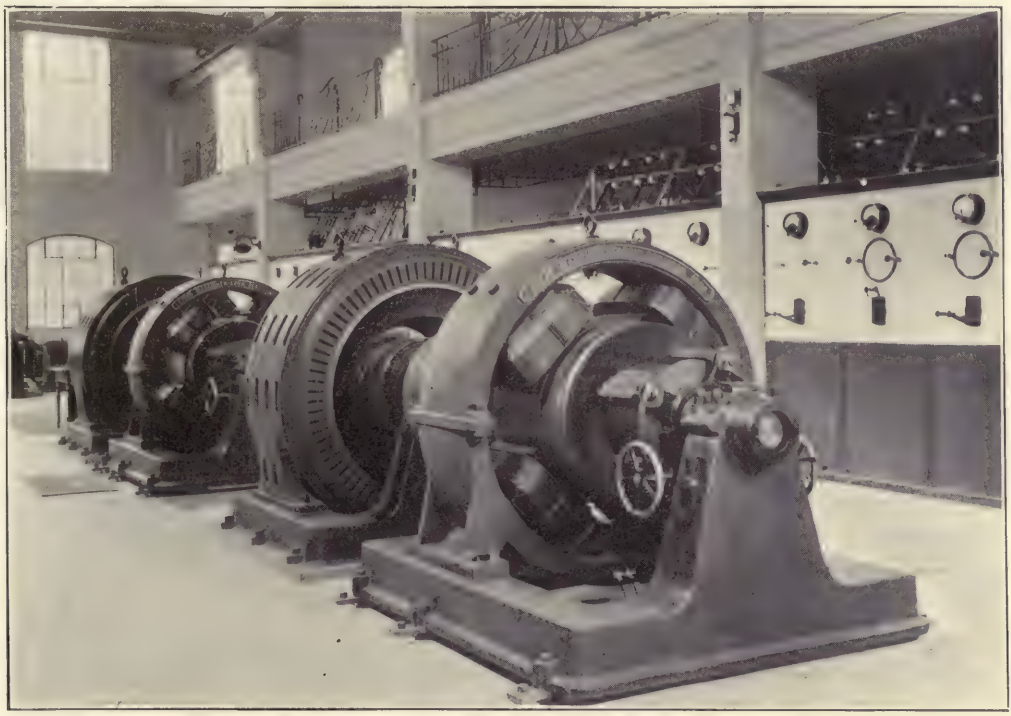


FIG. 4.—Motor Generator Sets. Substation "Steghof," Switzerland.

generator, an alternating current machine. The generator has more or less pairs of poles than the motor, depending upon the frequency desired. Sometimes an induction motor is substituted in place of the generator and made to rotate above or below its rated speed. The alternating current line is connected to the rotor of the motor, and if the rotor operates above its normal speed, the frequency is increased; if below, the frequency is decreased.

Frequency changers are not very much used; however, when they are employed, they are used in plants which run in parallel with others of different frequencies. A notable example in the use of frequency changers is in Montreal, Quebec.[1]

[1] Frequency Changers at Montreal, by B. A. Behrend, *Electrical World and Engineer*, Feb. 13, 1904.

"The City of Montreal, Quebec, obtains electric energy for power and lighting from three plants, which have three different frequencies. The Chambly power plant supplies alternating current at 66 cycles, the Lachine Hydraulic Land & Power Company generates alternating current at 60 cycles, and the Shawinigan Water & Power Company generates alternating current at 30 cycles. Since the consolidation of these three plants, a compromise frequency of 63 cycles has been adopted.

"At Shawinigan Falls there are installed two 3750-K.W. generators operating at 180 revolutions and 30 cycles, and generating 2300 volts two-phase. By means of transformers, the two-phase current is changed to three-phase 55,000 volts, which is transmitted from Shawinigan to Maisonneuve, a distance of 85 miles. In the substation at Miasonneuve, a suburb of Montreal, the 30-cycle, three-phase current is stepped down from 44,000 to 2300 volts. The long distance line between Shawinigan Falls and Maisonneuve is operated at the potential of 55,000 volts at the generating end, and 44,000 volts at the receiving end. The three-phase, high potential current is reduced by three transformers from 44,000 to 2300 volts.

"The five groups of frequency changers change the current from 2300 volts three-phase 30 cycles to 2300 volts three-phase 60 cycles. Fig. 5 is the 30-cycle motor;

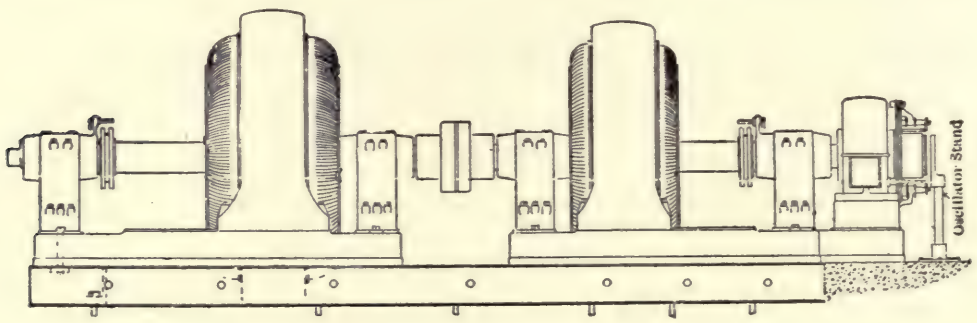


FIG. 5.—Outline of 1065-KW. Frequency Changers.

the machine to the right is the 60-cycle generator; the exciter shown on the right hand side of the set serves as a starting motor and also excites the two alternators. The rating of each set is 1068 K.W. at 2300 volts 60 cycles, 100 per cent power-factor, or 800 K.W. at 75 per cent power-factor. The speed of the frequency changers is 450 revolutions, the motor being an 8-pole machine, the generator a 16-pole machine.

"The frequency changers are started from the exciters, which are good for 75 K.W. at 120 volts. Although the excitation of each machine does not exceed 18 K.W. under any condition of load, it was deemed advisable to use large exciters in order to facilitate the starting of these sets, as at the moment of starting the current taken is quite considerable. A 30-cycle induction motor direct-connected to an 80-K.W. direct-current generator is used for the starting of the frequency changers.

"The operation in multiple of frequency changers is of considerable interest. Imagine a frequency changer to be in operation and that a second frequency changer

is to be connected in parallel with the first. Imagine that the first set is carrying full load and that the second set is to divide the load with it.

"The motor can be synchronized in the usual manner by adjusting the field current, so that the potential difference between the bus bars and the synchronous motor vanishes. If the generator is synchronized in the same way it is not possible to put a load on the machine. If the field current of the generator is diminished or increased the load of the frequency changer remains unaltered and the effect of changing the excitation results only in an increase of the cross currents between the two sets.

"Now then, in order to make the second frequency changer divide the load with the first, it becomes essential to abandon the usual way of paralleling. Let it be assumed that both sets are in operation and are dividing the load equally. The

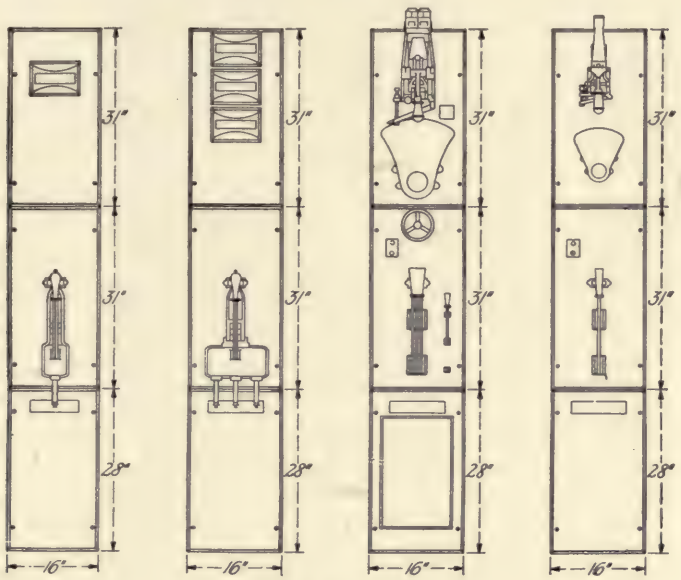


FIG. 6.—Typical Substation Switch Board Panels. 1. Incoming Line or A.C. Converter Panel. 2. Outgoing Line Panel. 3. D.C. Converter Panel. 4. D.C. Single Circuit Feeder Panel.

saturation curves of the machines being the same, it is clear that the exciting currents of the machines must also be the same if the load be distributed uniformly between them. As juggling the field currents after the machine has been thrown in parallel has no other effect than to increase the cross currents, it is evident that the field currents have to be adjusted properly before the machines are thrown in parallel. Hence, assume the first set in operation with 125 amperes excitation on the fields of the generator. To throw the second set in parallel with the first set, first synchronize the motor of the second set and then make the excitation of the generator of the second set, 125 amperes. The bus bar voltage on which the first set is operating is 2300 volts; the second set has the same excitation and the terminal voltage of its

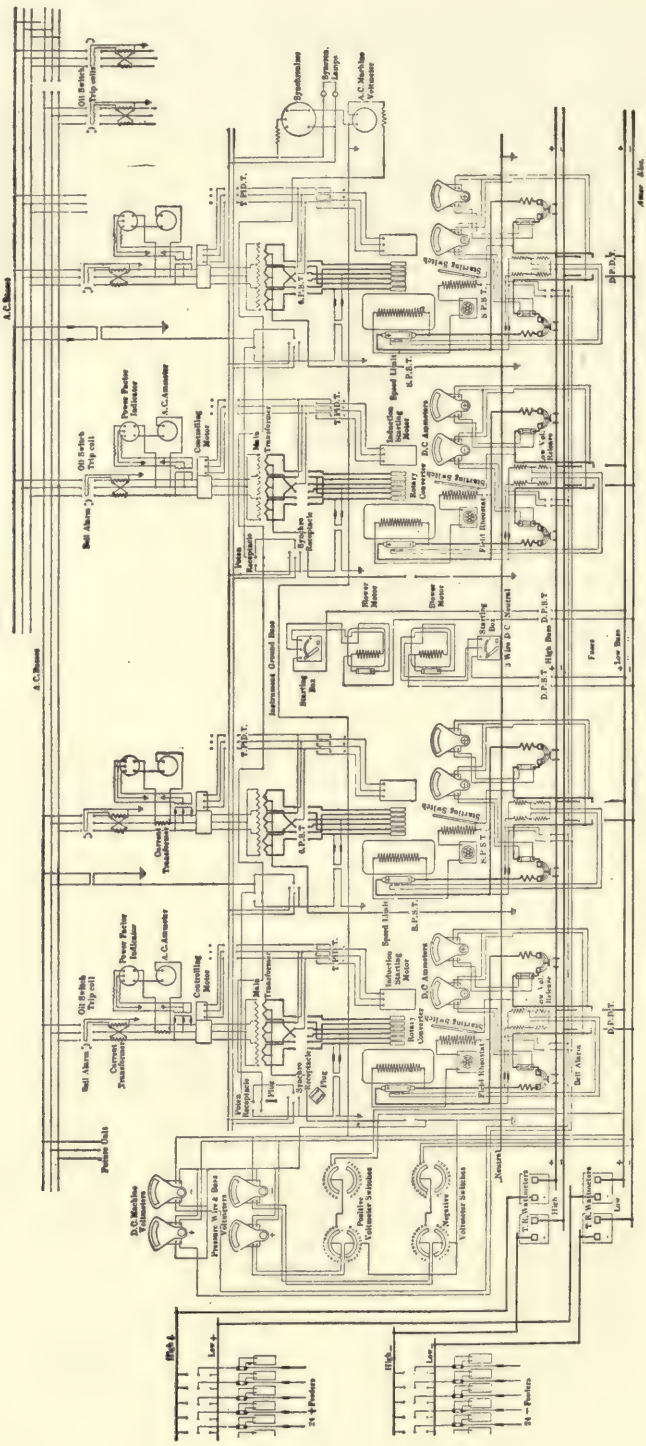


FIG. 7.—Wiring Diagram of the Waterbury Substation No. 2.

generator is, therefore, greater than the bus bar voltage on which the machine is to operate.

Assume the drop of the machine at its load to be 12 per cent; then the generator of the second set at 125 amperes excitation on its fields will generate 2580 volts. The switches must be closed between the two machines at these unequal voltages and the two sets will pull each other in parallel with the load distributed equally between them."

Switch Gear. The switch gear is similar to that of the main generating station. Each incoming feeder circuit has its own panel, and the equipment depends somewhat on the form of switch adopted, whether hand or electric operated. Fig. 6 shows typical substation panels one and two for alternating current; the former, for incoming high tension lines, having a lever for remote control automatically tripped oil switch, and one ammeter; the latter, for low tension distribution, having a three-pole, automatically tripped switch and three ammeters. No. 3 is the main converter panel, having a circuit-breaker with overload and low voltage release, one ammeter, one field rheostat, a potential receptacle, single-pole main switch, a double throw station-lighting switch, and the bottom panel contains a recording wattmeter. The last panel is a direct current feeder panel equipped with an overload circuit-breaker, ammeter, main switch, lightning arrester and choke coil, one potential receptacle by which the feeder voltage may be determined with the circuit-breaker open. This is used to advantage when the converters are started up on the direct current side.

The high and low tension alternating current bus bars must be separated if such are installed. In small stations the transformers are directly connected without the use of a bus. In large stations, high and low tension bus bars are placed on either side of the transformers, so that a converter may be operated without its own transformer when necessary.

Separate converters must be kept for lighting and railroad work, which means two direct current bus bar systems. They must, however, be interconnected that the converters can supply either systems.

What previously has been said under switchboards regarding flexibility, etc., applies also to substation equipment.

BIBLIOGRAPHY.

TRANSFORMERS FOR SINGLE AND MULTIPHASE CURRENTS. G. Kapp. 1906.

THE ALTERNATING CURRENT TRANSFORMER. F. G. Baum. 1903.

THE ALTERNATING CURRENT TRANSFORMER IN THEORY AND PRACTICE. J. A. Fleming. 1900.

PRINCIPLES OF THE TRANSFORMER. F. Bedell. 1908.

THE SERIES TRANSFORMER. E. S. Harrar. *Electrical World*, May 16, 1908.

THE CHOICE OF TRANSFORMERS FOR CENTRAL STATIONS. L. A. Sterrett. *Electrical World*, May 2, 1908.

THE CENTRAL STATION DISTRIBUTING SYSTEM. H. B. Gear and P. F. Williams. *Electrical Age*, February, 1908.

SOME FEATURES OF EUROPEAN HIGH TENSION PRACTICE. Frank Koester. *Electrical Age*, December, 1908.

THE DETERMINATION OF THE ECONOMIC LOCATION OF SUB-STATIONS IN ELECTRIC RAILWAYS. Gerard B. Werner. *Proc. Am. Inst. E. E.*, May, 1908.

RECEIVING STATION OPERATED FROM HIGH-TENSION TRANSMISSION LINE. *Electrical Age*, July, 1908.

INSTRUCTIONS TO OPERATORS IN RAILWAY CONVERTER SUB-STATIONS. J. E. Woodbridge. *Electric Railway Journal*, June 13, 1908.

PROTECTION OF THE INTERNAL INSULATION OF A STATIC TRANSFORMER AGAINST HIGH FREQUENCY STRAINS. W. S. Moody. *Proc. Am. Inst. E. E.*, May, 1907.

RELATIVE MERITS OF THREE-PHASE AND ONE-PHASE TRANSFORMERS. H. W. Tobey. *Proc. Am. Inst. E. E.*, April, 1907.

RELATIVE ADVANTAGES OF ONE-PHASE AND THREE-PHASE TRANSFORMERS. J. S. Peck. *Proc. Am. Inst. E. E.*, April, 1907.

FORCED OIL AND FORCED WATER CIRCULATION FOR COOLING OIL INSULATED TRANSFORMERS. C. C. Chesney. *Proc. Am. Inst. E. E.*, April, 1907.

A.E.&M
UNIV. OF C

CHAPTER X.

LINE PROTECTION.

LIGHTNING ARRESTERS.

Purpose. To guard against interruption of service of the generating plant or substation, the electrical apparatus of same must be protected, particularly against atmospheric discharges. This is done by providing the transmission system with lightning arresters or some form of grounding device. The function of same is to act as a relief vent.

Various sources of disturbances (particularly where the transmission line runs through sections of country of different altitudes), the chief of which is lightning, causing surges and oscillations in the circuit of such frequency and high potential as will endanger the apparatus in the generating plant, substation or probably both.

Lightning Discharges. Lightning, as commonly understood, means the electric discharges from cloud to ground, or from cloud to cloud, but the word "lightning" as applied to electric circuits, means much more than this. It includes, besides the lightning referred to, disturbances due to static unbalancing of the circuit and surges, that is, disturbances in the flow of generated power, brought about by various causes and depending for their energy on the power of the generating system. A very small per cent of these electrical disturbances results from direct strokes, the far greater number resulting from induction by charged clouds suddenly discharging or perhaps from the static charges collected from rain, snow or fog drifting across the line.

Regardless of their source all static disturbances on transmission lines are characterized by abnormal potentials and abnormal frequencies.

Principle of Arresters. The lightning arrester must permit sufficient freedom of escape of the charge from transmission lines so as to limit their potential to a safe value. To do this, a vent is required which will permit a very large flow of current when the potential is above a certain value, but which will suppress this flow of current quickly, quietly, and completely as soon as the potential has resumed a normal value. In other words, the arrester must permit the escape of the abnormal surge, but should preferably take no current whatever and consequently cause no additional disturbance or drop in voltage.

In general, a lightning arrester is made up of three elements, as follows: An air gap, a current limiting element and an arc suppressing device. Two of these elements are always present, and usually the other is combined in some form with the other two. The air-gap holds the voltage ordinarily, but is broken over by any great excess potential, thus permitting current to flow. The current limiting element

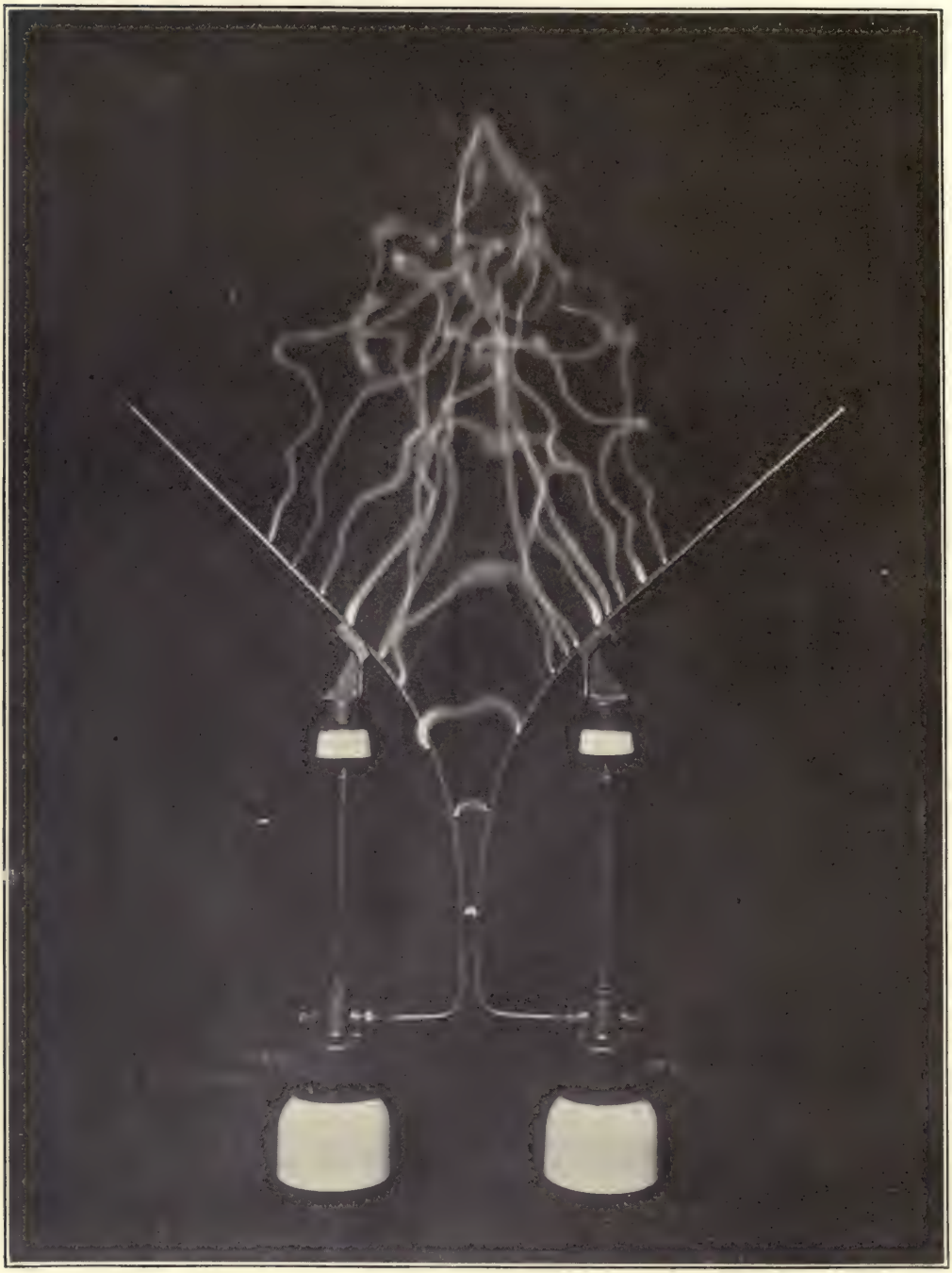


FIG. 1.—Siemens-Schuckert Horn Lightning Arrester. Showing Principle of Action.

usually appears in the form of a series resistance of some kind which limits the power current to a reasonable value. The arc-suppressing device is provided by some modification of the air-gap, and may consist of a magnetic blow-out, a mechanical arrangement by which the length of the gap is increased until the arc breaks (horn type), or non-arc-metal gaps consisting of a number of small cylinders with the proper spacing between them.

Horn Lightning Arresters. In Continental Europe, where it originated, the horn type lightning arrester has been extensively used since the early stages of electric transmission. It is based on the principle that a short-circuited arc once started at the narrow gap between the horns, the heat of the arc will cause it to travel upwards along the members of the horn and break by reason of its attenuation. In some recent practice, auxiliary apparatus is used in connection with it, such as water flow grounders, oil resistances, choke coils, relays, condensers, etc.

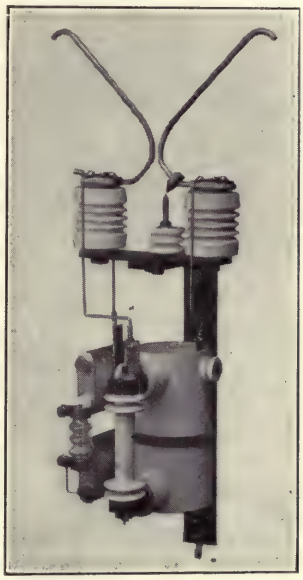


FIG. 2. — Siemens-Schuckert Horn Gaps with Micrometric Setting.

Fig. 2 shows a Siemens-Schuckert Relay Horn Lightning Arrester with condensers, Tesla transformer, rheostat, and automatic blow-out, etc. The horns are placed 3 to 4 mm. apart, which is the lowest practical setting, because dust or other particles may collect and cause it to discharge when set lower. The gap of 3 to 4 mm. will cause the arrester to discharge under ordinary operating conditions at 8000 volts, but with the use of the auxiliary apparatus, it will discharge at 3000 volts and lower without changing the setting of the horns. This is accomplished by the discharge of an auxiliary gap set off by two condensers; the auxiliary discharge causes high frequencies to be set up in the Tesla transformer which starts the main gap. By this means the main gap can be set to several times the opening otherwise required for breakdown at 2000 or 3000 volts. Fig. 3 shows the arrangement of six such arresters connected to an oil resistor. Three of the arresters are connected in " Y " to relieve the line of lightning discharges and three are connected in delta between phases to relieve one another of unbalancing effects.

The American type of horn lightning arresters is usually built on a large scale and preferably installed out of doors. Fig. 4 shows such an arrester as installed by the American River Electric Company, California. They are installed on the 40,000-volt transmission line, and are made of galvanized iron gas-pipe mounted on insulators on a pole construction; the gap is 2.25 inches. The horns are grounded through a 25-gallon water tank with a film of oil on top to keep down evaporation. Experience has proved that pure water in the tank gives better satisfaction than water with salt. The company reports: " In one instance they discharged several times in succession, the arc traveling halfway up before breaking. Every discharge had the same

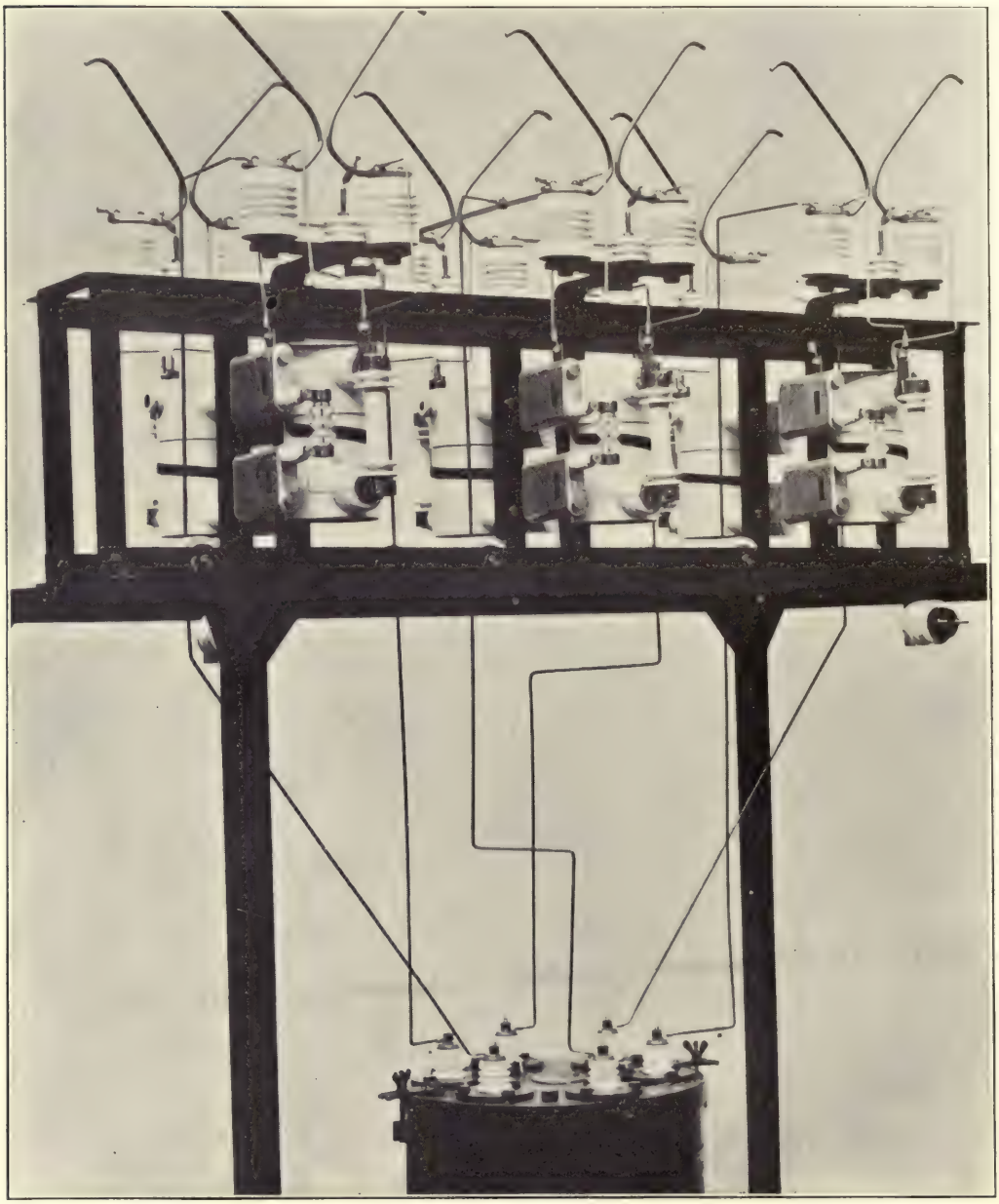


FIG. 3.—Application of Siemens-Schuckert Lightning Arresters with Micrometric Setting, and Oil Rheostat.

effect as a temporary short-circuit, causing the voltmeter to swing entirely across the scale, and the lights to dim to perhaps half candle power. We have had no trouble from these arresters, no damage done by lightning, and consider the arrester as satisfactory for high voltage as any now in use."

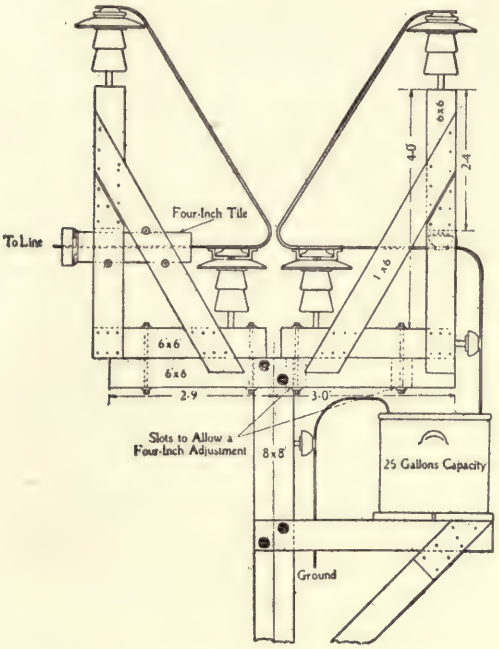


FIG. 4.—Construction of a Horn Type Arrester, American River Electric Company.

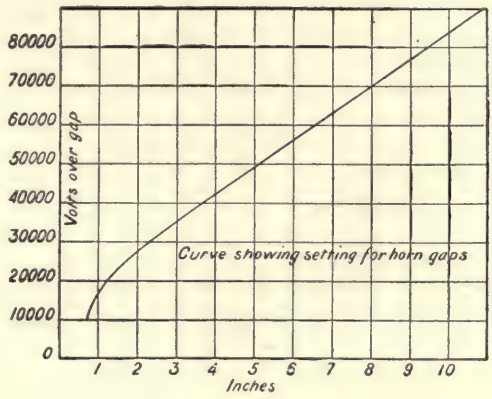


FIG. 5.—Curve Showing Setting of Horn Gaps.

Horn-Gap Setting. In Fig. 5 is shown a curve which gives the proper gap-lengths for horn-gaps when used on certain voltages. According to American ideas, horn-gaps should not be used for potentials lower than 13,500 volts, since the gap is so small

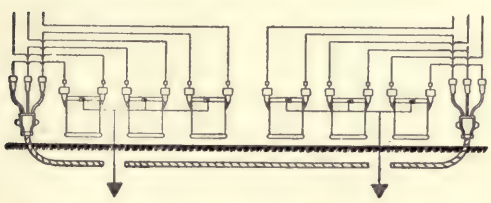


FIG. 6.—Protection of a Combined Overhead and Underground Line, Using Oil-Immersed Choke Coils.

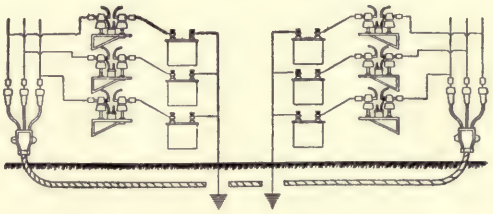


FIG. 7.—Protection of a Combined Overhead and Underground Transmission Line, Using Horn Gaps and Oil-Immersed Resistances.

that the arc will not rise properly and break. Some latitude is allowable in the setting of the horn-gaps. The gap must be so set that small arcs will not strike back and rise again repeatedly.

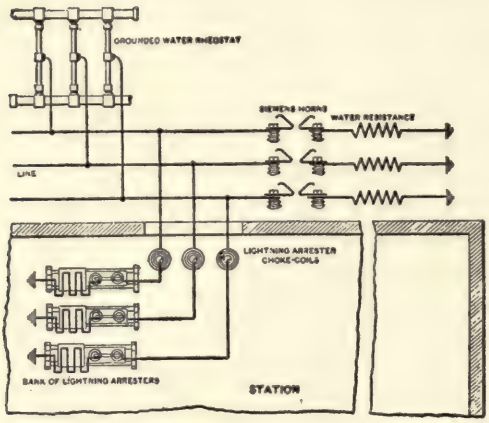


FIG. 8.—Scheme of Station Protection by Torchio.

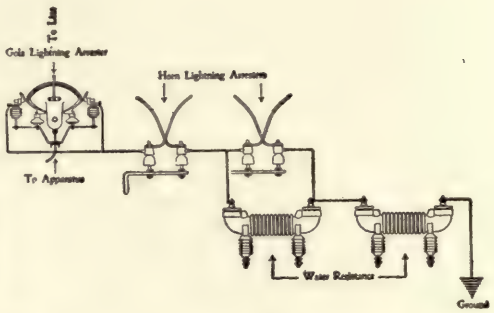


FIG. 9.—Arrangement of Protecting Apparatus of 3000-volt Circuit as Proposed by Gola.

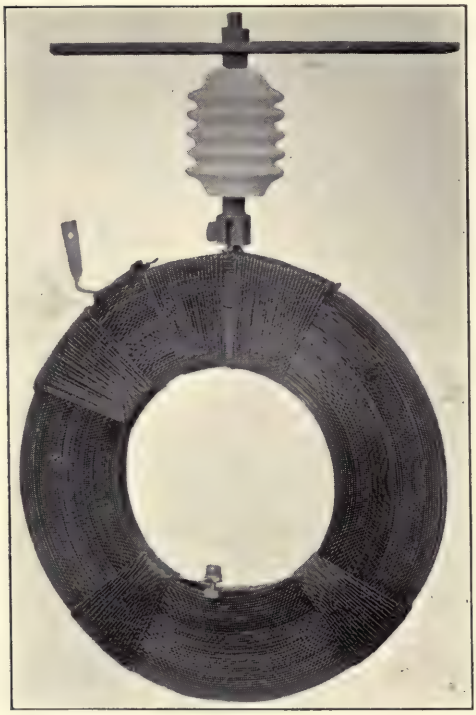


FIG. 10.—Flat Choke Coil.

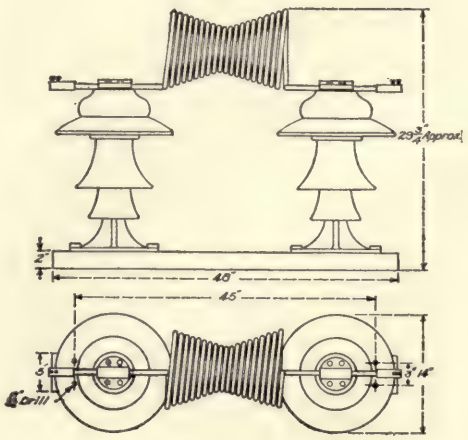
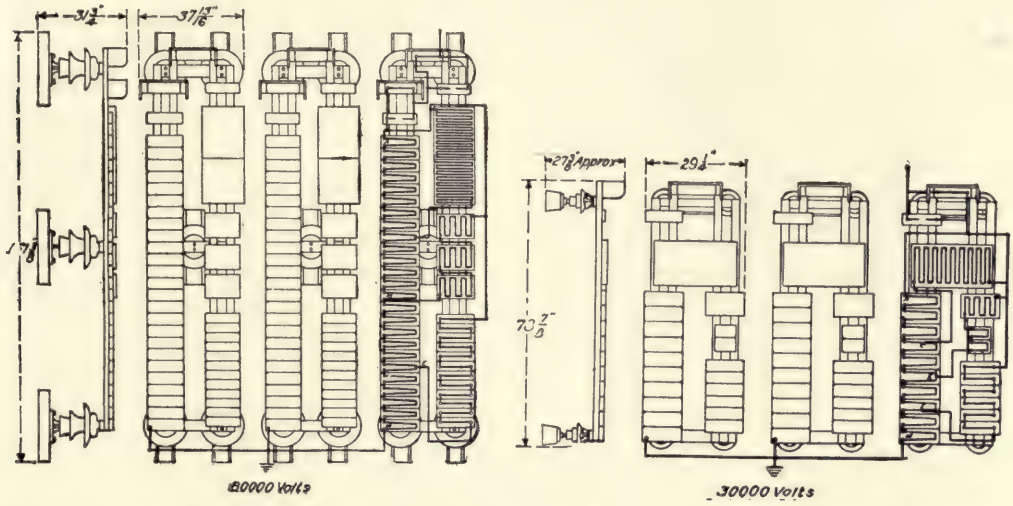


FIG. 11.—Hour Glass Type of Choke Coil.

Choke Coils. Choke coils are installed to take care of surges in the line and are always used in connection with the various kinds of lightning protective devices. The advantages of using a choke coil are, as there is normally no voltage between the turns, and there is no tendency to hold a short-circuit in case of a surface momentary discharge, it permits of a cheaper transformer construction.

They are made in various forms, such as flat copper strips wound in spiral, copper wire wound spirally in the form of an hour-glass, or in cylindrical spiral form. In most forms the turns are insulated from one another.

Multigap Arresters. Of the various makes of multigap lightning arresters, the differences between them amount to but little. They are built to operate on the same principles, which are as follows: The greater the value of the dynamic current, the greater the number of gaps required to extinguish the arc. Any arc is unstable



FIGS. 12 and 13.—Three Phase Multigap Lightning Arresters, General Electric Company.

and can be extinguished by placing a properly proportioned resistance in parallel with it. Further, the higher the frequency of the lightning oscillations, the more readily will the multigap respond to the potential.

Being made up of units, the multigap arrester can be built for all commercial voltages. Those used on circuits below 6000 volts are classified as low tension, and those above, as high tension arresters.

Action of Multigap Arrester. The essential elements of this arrester are a number of cylinders spaced with a small air-gap between them, and placed between line and ground, and between line and line. In operation, the multigap arrester discharges at a much lower voltage than would a single gap having a length equal to the sum of the small gaps.

In explaining the action of multigaps, there are three things to take into consideration; the transmission of the static stress along the line of the cylinders; the sparking of the gaps; the action and duration of the dynamic current which follows the spark,

and the extinguishment of the arc. A spark may be defined as conduction of electricity by the air, and an arc as conduction of electricity by vapor of the electrode.

The cylinders of the multigap arrester act like plates of condensers in series. This condenser function is the essential feature of its operation. When a static stress is applied to a series of cylinders between line and ground, the stress is instantly carried from end to end. If the top cylinder is positive it will attract a negative charge on the face of the adjacent cylinder and repel an equal positive charge to the opposite face, and so on down the entire row.

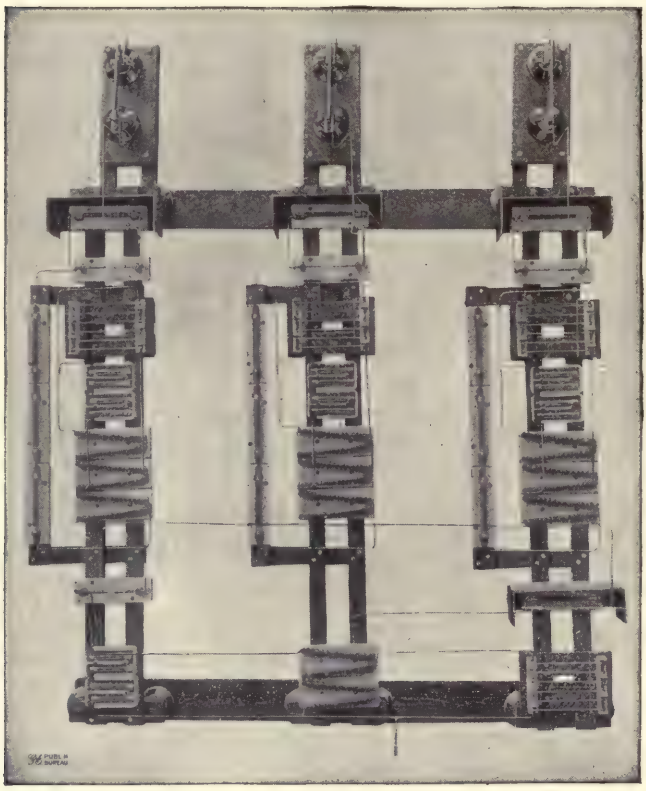


FIG. 14.—Graded Shunt Resistance, Multigap Lightning Arrester, General Electric Company.

The second cylinder has a definite capacity relative to the third and also to the ground; consequently the charge induced on the third cylinder will be less than on the second, due to the fact that only part of the positive charge on the second cylinder induces negative electricity on the third, while the rest of the charge induces negative electricity to the ground. Each successive cylinder, counting from the top of the arrester, will have a slightly less charge of electricity than the preceding one. This condition has been expressed as "a steeper potential gradient near the line."

The quantity of electricity induced on the second cylinder is greater than on any lower cylinder, and its gap has a greater potential strain across it. When the potential across the first gap is sufficient to spark, the second cylinder is charged to line potential and the second gap receives the static stress and breaks down. The successive action is similar to overturning a row of nine-pins by pushing the first pin against the second. This phenomenon explains why a given length of air-gap concentrated in one gap requires more potential to spark across it than the same total length made up of a row of multigaps. As the spark crosses each successive gap, the potential gradient along the remainder readjusts itself.

When the sparks extend across all the gaps, the dynamic current will follow if, at that instant, the dynamic potential is sufficient. On account of the relatively greater current of the dynamic flow, the distribution of potential along the gaps becomes equal, and has the value necessary to maintain the dynamic current arc on a gap. The dynamic current continues to flow until the potential of the generator passes through zero to the next half cycle, when the arc-extinguishing quality of the metal cylinders comes into action. The alloy contains a metal of low boiling point which prevents the reversal of the dynamic current. It is a rectifying effect, and before the potential again reverses, the arc vapor in the gaps has cooled to a non-conducting state.

Installation of Multigap Arresters. The multigap arresters may be installed on delta connected and also on "Y" connected circuits, with the neutral grounded or ungrounded. The difference lies in the use of a fourth arrester leg between the multiplex connection and ground on underground systems.

The reason for introducing the fourth leg is evident, for if one leg becomes accidentally grounded, the full line potential would be thrown across one leg if the fourth or ground leg were not present. On a "Y" system with a grounded neutral, the accidentally grounded phase causes a short-circuit of the phase and the arrester is relieved of the stress by the tipping of the circuit breaker. Briefly stated, the fourth or grounded leg of the arrester is used when, for any reason, the system could be operated even for a short time, with one phase grounded. In protecting 2-phase 4-wire circuits, two single phase, multiplex connected arresters are used; when protecting 2-phase 3-wire circuits, two single phase arresters are connected in between the outside leg and the common leg, no multiplex cross connection being between the outside legs. As much wall space as possible must be provided, and plenty of room in front must be left for the operator. The following minimum separation distances, recommended by the General Electric Company for the past few years, have proved entirely satisfactory.

TABLE I. — GIVING PROPER SPACE BETWEEN ARRESTERS.

Volts.	Distance between live parts of adjacent phases.	Minimum distance between centers.[1]
	Inches.	Inches.
6,600	8	28
10,000	8	28
12,500	8	33
15,000	10	35
20,000	12	37
25,000	18	48
30,000	22	52
35,000	26	56
40,000	28	62
45,000	32	67
50,000	36	72
60,000	40	78

[1] If barriers are used, the width of barriers should be added to distances given.

It is advisable to install arresters in a dry place, and before assembling them, the wooden supports, insulators, etc., must be thoroughly dried of all moisture which may have collected.

Fluid Arresters. There are two different kinds of fluid arresters in American practice. In one, the components are submerged in oil in a steel tank, and known as Aluminum Arresters (General Electric Company): in the other, the components are incased in an empty porcelain jar, and known as the Electrolytic Arrester (Westinghouse Electric and Manufacturing Company). The principle of both is practically the same. It consists of a series of concentric aluminum pans, placed one above the other, separated by an electrolyte, usually a borax solution.

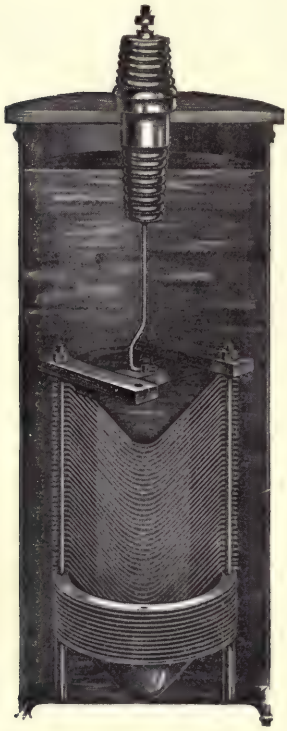


FIG. 15.—General Electric Company's Aluminum Lightning Arrester.

Experiments have been made for a number of years with a film, which may be formed on aluminum plates, when treated with certain electrolytes. This film being very thin, that is, comparable in thickness with a wave length of light, its electrostatic capacity as a condenser is very great. If the electromotive force is constant, only leakage current passes through, but if it is alternating, there is a leakage and a charging or condenser current superimposed.

It was discovered that this film has a very desirable characteristic for lightning arrester purposes, in that it has an apparent resistance of a very high value when moderate voltages are impressed upon it. When the voltage or pressure reaches a certain value, however, this film breaks down in myriads of minute punctures making almost a short circuit for these higher voltages. As soon, however, as the voltage is reduced again, the minute punctures seal up at once, and original high resistance reasserts itself. It may be seen that for electrical pressure, this action is exactly the same as that of a safety valve on a boiler.

In the aluminum arrester, each cell is designed to operate normally at 300 volts with a very small leakage current, and with a permanent critical value of 420 volts, that is, the voltage at which the film opens and allows a free and heavy discharge is 420, and the permanent critical value is thus 40 per cent above the normal operating voltage.

If the potential rises to any value greater than 300 and less than 420 volts, a temporary critical value is reached and the film allows the arrester to discharge for a short time. A thicker film is soon formed and the leakage current is decreased to a small amount. When the line potential again becomes normal, this extra thickness of the film gradually dissolves. If the voltage continues to rise, this process of forming a temporary critical film continues until the permanent critical value, 420 volts, is reached, when the cells discharge freely, allowing a heavy rush of current. The

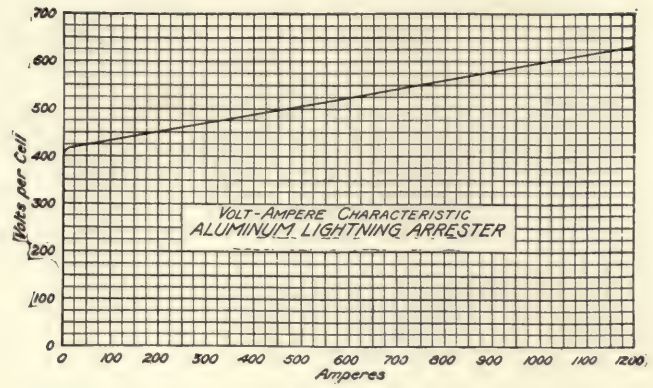


FIG. 16.—Discharge Rate Above Permanent Critical Value.

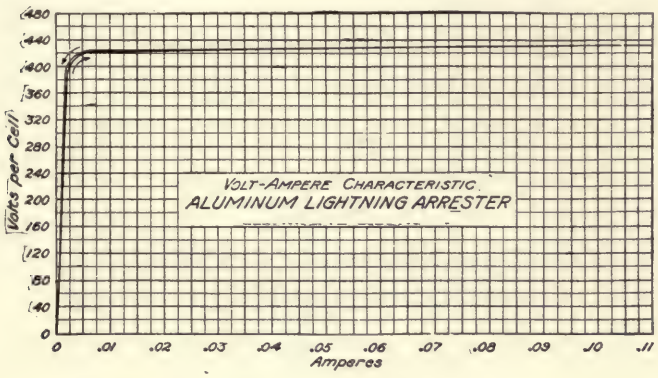
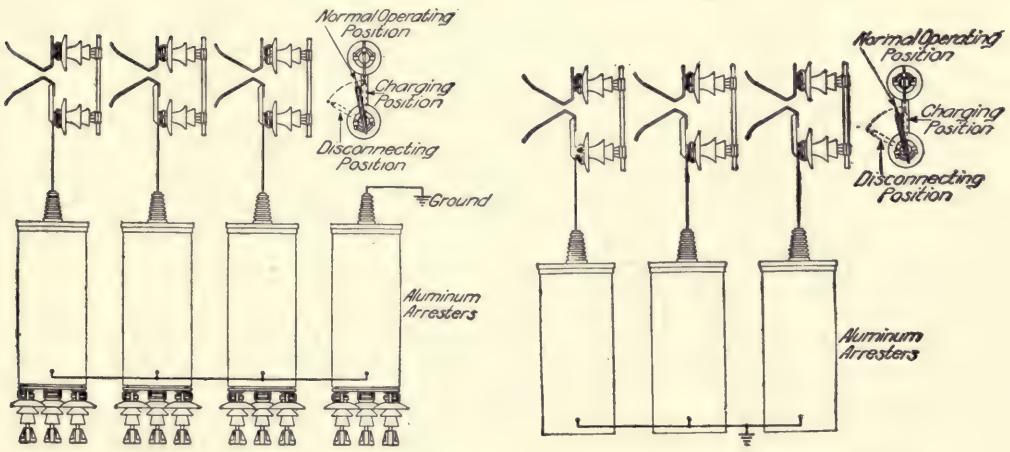


Fig. 17.—Characteristic Curve at Permanent Critical Value of General Electric Aluminum Arrester.



For Delta or Ungrounded Y System. *For Grounded Neutral System.*

FIGS. 18 and 19.—Arrangement of General Electric Company's Arresters. In the Installation the Bases of the Horn Gaps are, of course, Horizontal.

plate area of the cells is sufficient to discharge a quantity of electricity many times greater than that which would be liberated by an ordinary induced lightning stroke.

The upper cut in Fig. 16 is a volt-ampere curve showing the characteristics of a film which has been formed up to its permanent critical value; the lower (drawn to a

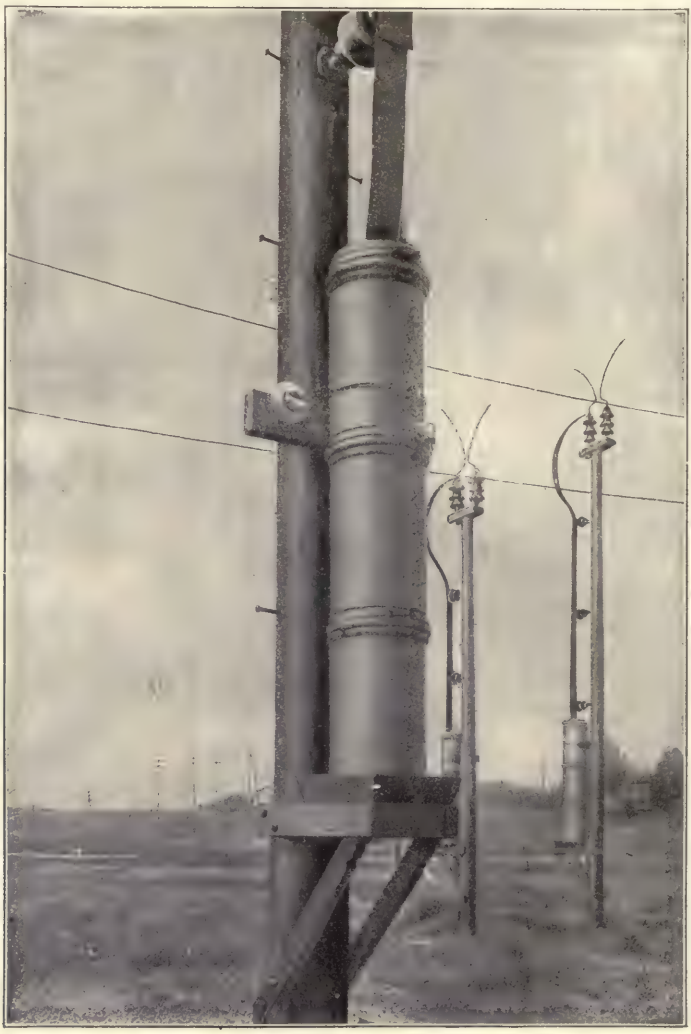


FIG. 20.—Outside Installation of Westinghouse Electrolytic Lightning Arresters.

different scale) shows the discharge rate above the permanent critical value. Sufficient cells are placed in series on circuits of any given voltage to allow a normal voltage of 300 volts per cell.

The arresters are connected permanently between line and ground. A multi-gap or horn-gap, set at a suitable value above line potential, is inserted in series, and

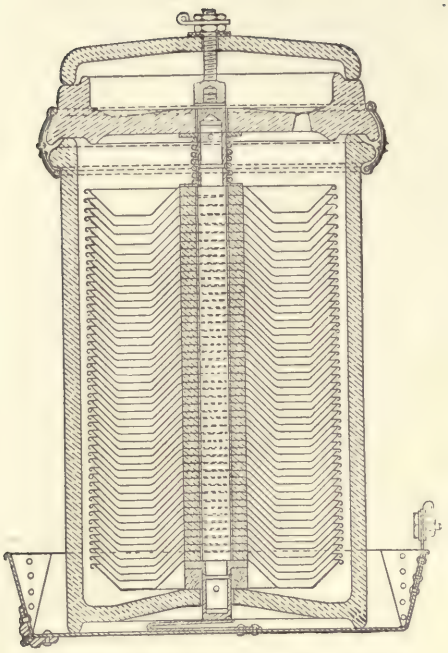


FIG. 21.—Westinghouse Electrolytic Lightning Arrester.



FIG. 22.—Horn Lightning Arresters with Water Flow Grounder at Substation Steghof, Switzerland.

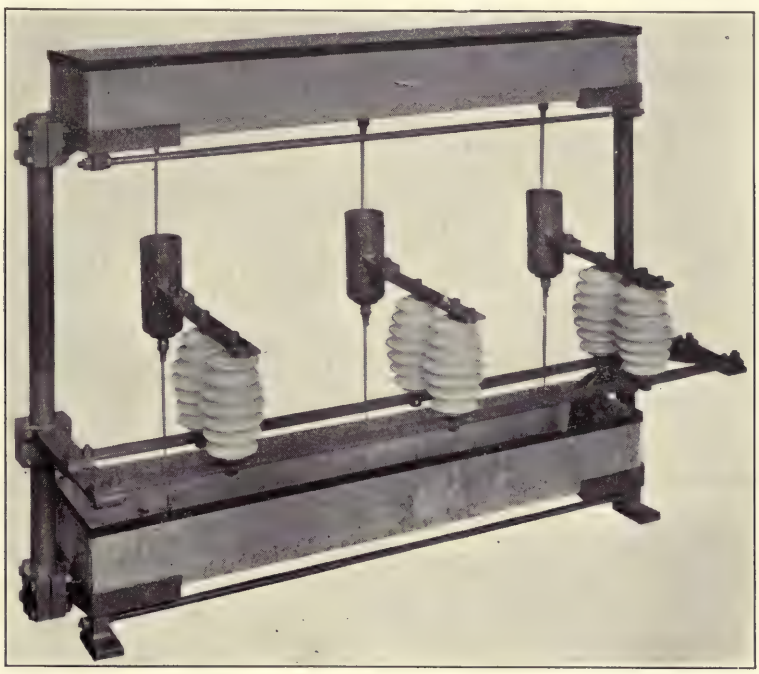


FIG. 23.—Oerlikon Water Flow Grounder.



FIG. 24.—50,000-volt Alioth Waterflow Grounder at Step-up Station, Piattamala, Italy.



FIG. 25.—Bank of Horn Gaps, Choke Coils, and Water Flow Grounders installed at the Vandoise Motor Power Company's Plant at Lakes of Joux and Orbe, Switzerland.

prevents the arrester from being subjected continuously to the line voltage. In this way leakage is prevented during normal operation, and a longer life is assured. The accompanying illustrations show the application of these types of lightning arresters.

Frequently the horn arrester is connected to water flow grounders. Fig. 22 shows such an arrester as installed by the Oerlikon Company, in connection with a 27,000-volt transmission line. The grounding device consists of a pair of glass tubes through which water is continuously flowing. Another arrangement of a water flow grounder as installed by The Alioth Company, in connection with the 50,000-volt Swiss-Italian transmission system, is seen in Fig. 24. It has been installed in addition to horn-lightning arresters and choke coils, to take care of light surges in the line and to maintain uniform line pressure. This apparatus consists of a nozzle or jet of water (from a spring), playing against a baffle plate connected to the line. The stream of water is three-eighths of an inch in diameter, 28 inches high, and allows a leakage of 0.1 ampere. Ammeters are inserted in the line connection to detect failures in grounding.

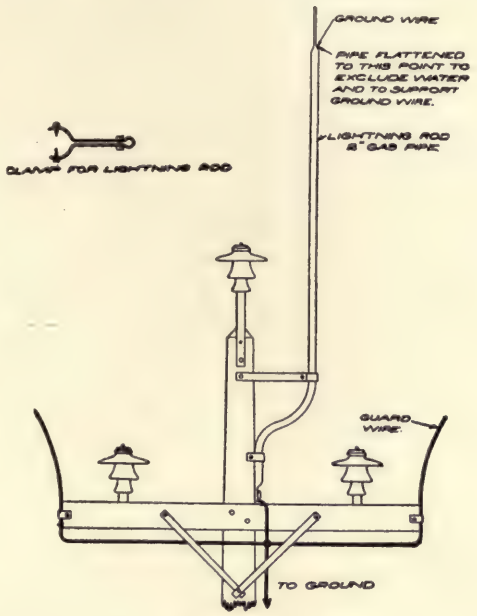


FIG. 26.—Lightning Rod.

Water-flow grounders, in different forms, have been used successfully for a number of years on the Continent of Europe. However, in America its use has not been advocated, for the reason that the assumption of the failure of water supply points out that the apparatus is inefficient. This argument is not quite justifiable, as the water may be drawn from the same supply as the turbines, and in substations, usually located in or near cities, water from the city mains can be used. It is the practice in European countries to make use of the water which circulates through the cooling coils in the oil transformers. Further, the water from nearby springs is oftentimes available.

Location of Arresters. The main generating station and all substations must be equipped with lightning arresters. Practice of recent years shows that it is good policy to install more than one form of arrester, for instance, a combination of multi-gap and horn type for direct lightning strokes; choke coils and fluid arresters to take care of slight atmospheric discharges and surges.

Some power plants are equipped with all four of the above-mentioned forms, for example, the Ontario Power Company, which has the electrolytic form of fluid arrester, and gaps of the different horns set for various voltages. In a recently installed 7000/50,000-volt transformer station at Piattamala, Italy, the station protection is as

follows: Flat choke coils are placed on both sides of the transformers in connection with horn lightning arresters provided with water rheostats; for taking up lighter static and atmospheric discharges, cylindrical choke coils with non-inductive resistances are provided. Finally, as all surges will create more or less variation in pressure, water jet grounders are installed to maintain uniform pressure.

The location of lightning protection devices is a matter of opinion. In American practice, the choke coils and multigap arresters are located inside the station, while the fluid and horn-gap arresters are outdoors. In Europe, the practice is to locate all the lightning protection apparatus inside of the stations, with exception of those on the line. Even these are sometimes placed in section houses.

The transmission line itself must be protected against lightning either by horn-lightning arresters at frequent intervals (about 2 or 3 miles), or by the overhead guard wire. The latter is more frequently used on wooded pole line construction. Where no guard wire is used on wooden pole lines, the individual poles must be provided with a lightning rod extending some ten to twelve inches above the top, sometimes fastened to an iron pole-cap.

Guard wires, and all lightning arresters, must be well grounded by a copper wire having a short and straight run to ground.

The end may be wound in a coil or connected to a copper plate buried in the ground. Flat copper strip is sometimes used in place of copper wire. The efficiency of the grounding wire is increased if the earth plate is buried in moist ground.

BIBLIOGRAPHY.

LIGHTNING-RODS AND GROUNDED CABLES AS A MEANS OF PROTECTING TRANSMISSION LINES AGAINST LIGHTNING. Norman Rowe. *Proc. Am. Inst. E. E.*, May, 1907.

PRACTICAL TESTING OF COMMERCIAL LIGHTNING ARRESTERS. P. H. Thomas. *Proc. Am. Inst. E. E.*, June, 1907.

A PROPOSED LIGHTNING ARRESTER TEST. N. J. Neall. *Proc. Am. Inst. E. E.*, June, 1907.

PROTECTIVE APPARATUS ENGINEERING. E. E. F. Creighton. *Proc. Am. Inst. E. E.*, June, 1907.

PROTECTION AGAINST LIGHTNING, AND THE MULTIGAP LIGHTNING ARRESTER. D. B. Rushmore and D. Dubois. *Proc. Am. Inst. E. E.*, April, 1907.

NEW PRINCIPLES IN THE DESIGN OF LIGHTNING ARRESTERS. E. E. F. Creighton. *Proc. Am. Inst. E. E.*, 1907.

SOME FEATURES OF EUROPEAN HIGH-TENSION PRACTICE. Frank Koester. *Electrical Age*, December, 1908.

PART III.

(APPENDIX.)

MODERN AMERICAN AND EUROPEAN HYDROELECTRIC DEVELOPMENTS.

A.E.&
UNIV. o

APPENDIX.

TYPICAL HYDROELECTRIC PLANTS.

THE POWER PLANT AND TRANSMISSION SYSTEM OF THE ONTARIO POWER COMPANY.

According to Zoelly, in a paper before the Engineering and Architectural Society of Zurich, Switzerland,[1] there is no accurate data on the flow of water over Niagara Falls; it is estimated that the flow is one hundred million cubic meters per minute (three thousand five hundred and thirty million cubic feet). This is sufficient to develop 16,800,000 HP., or, figuring on an efficiency of 75 per cent, 12,600,000 HP.[2] Although this enormous amount of power is available, and in spite of the number of large plants already erected, only a small percentage of the water is utilized.

Since 1890, when the International Power Commission met to decide upon the utilization of the water of Niagara, great progress has been made in water-power development. On April 4, 1895, the first 5000-HP. turbine of the Niagara Falls Power Company was set in motion. The many plants now located around Niagara Falls give ample proof of the success of this first installation, especially as three other Niagara plants have been built on the same lines. It will be noticed by studying the accompanying drawing, that on the American side are located, besides several small, four large installations; two above the rapids, and two below the falls in the gorge. The law of the New York State Reservation, 1885, stipulated that the big power developments had to be one mile away from the Falls. On the Canadian side, conditions were different; the whole of Victoria Park was thrown open wide to the development of power from the Horse-Shoe Falls.

Starting on the American side, above the Falls, are located power houses Nos. 1 and 2 of the Niagara Falls Power Company. These plants are located on either side of an indented forebay about a mile and a quarter above the Falls. The turbines in station No. 1 are of the 5000-HP., vertical type, located at the bottom of a pit, and operate under a head of about 135 feet. There are ten units installed. Power house No. 2 is designed on the same principle and contains ten 5500-HP. units. The tailrace of both plants empties into a tunnel 1000 feet long and discharges into the gorge at the side of the pillar of the steel arch bridge. It might be of interest to state, that after thirteen years of continuous operation, the lining, of ordinary brick, has been in no way damaged. Beneath the Falls at the water's edge on the American side, are power houses Nos. 2 and 3 of the Niagara Falls Power and Manufacturing Company.

On the Canadian side, the intake of the Ontario Power Company plant will be

[1] Neuere Turbinenanlagen. *Zeitschrift des Vereines deutscher Ingenieure*, 1901, p. 1239.

[2] Prof. W. C. Unwin made a rough estimate of 7,000,000 HP.

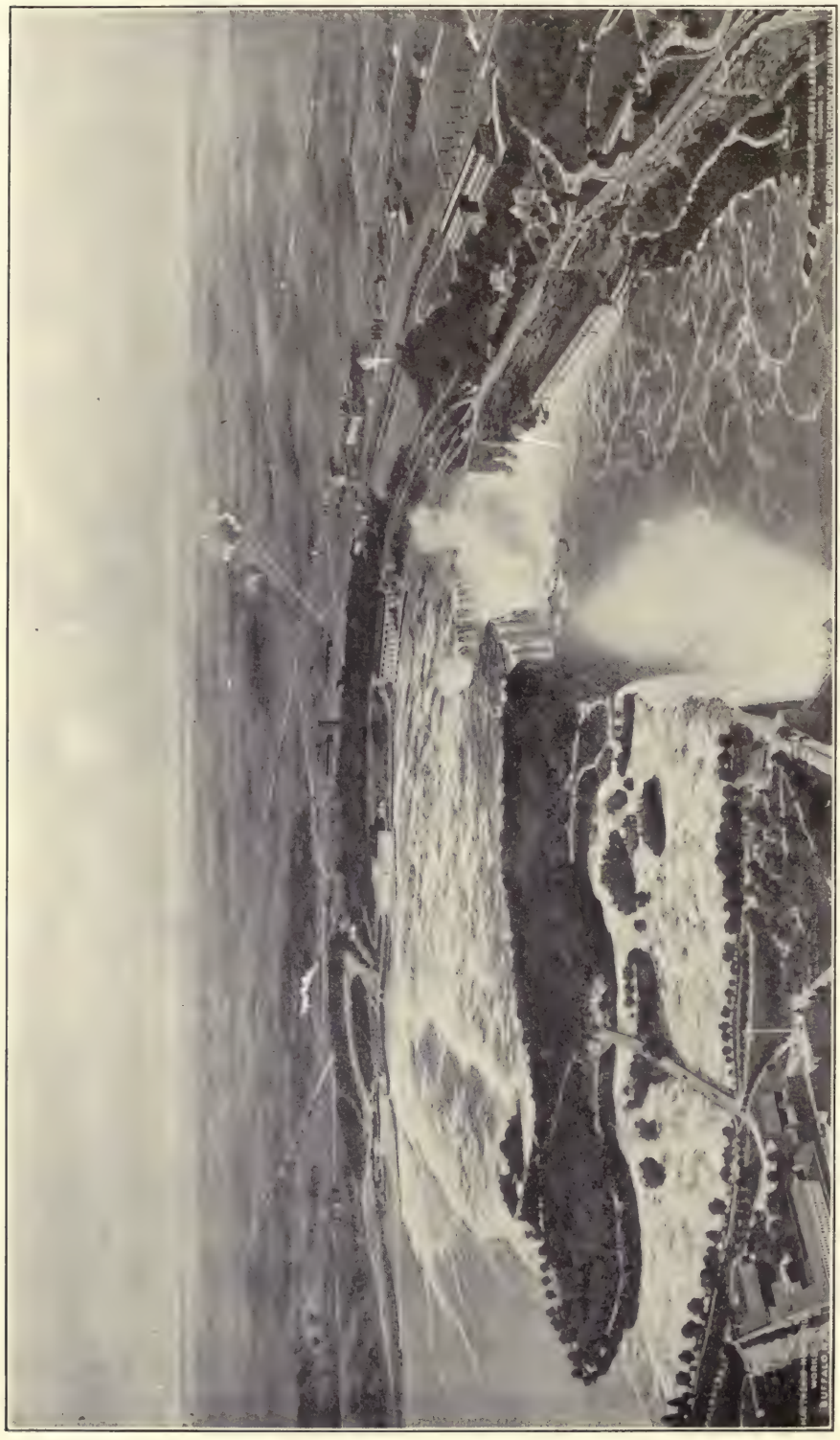


FIG. 1.—Bird's Eye View of Niagara Falls, showing the Power Developments on Canadian Side.

observed to be the farthest above the Horse-Shoe Falls. Below this is the plant of the Electric Development Company. It is equipped with vertical turbines similar to those of the Niagara Falls Power Company. The tailrace discharges into the Gorge at the base and behind the Horse-Shoe Fall. Below this power plant is that of the Canadian-Niagara Power Company, which is allied with the Niagara Falls Power

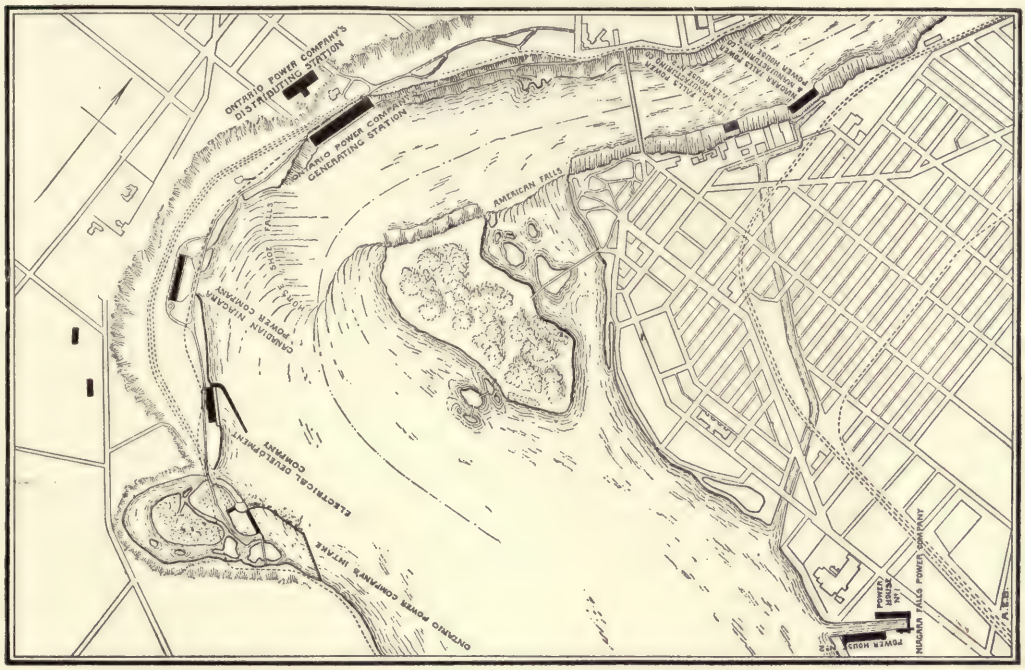


FIG. 2.—Map of Niagara Falls, showing Location of Power Developments.

Company. It is designed for vertical turbines with the general arrangement as the three above mentioned. The water from this plant is discharged into the Gorge at the foot of Table Rock Cliff. The four plants above the Falls are identical in many respects.

Ontario Power Plant.[1] The largest and most prominent power plant contemplated is that of the Ontario Power Company, located on the Canadian side of the Falls. There is no installation in the world which exceeds it in capacity. The power house is located in the Gorge near the Table Rock Cliff, and draws its water above the Falls among the Dufferin Islands. The ultimate capacity of the plant will exceed 200,000 HP. This power is controlled and distributed, at 60,000 volts, from an isolated distributing station, situated on the cliff some 600 feet away and 260 feet above the generating station.

Forebay. The forebay or intake is about 600 feet long, stretched across the inlet of Dufferin Islands and practically parallel to the main stream. The deflecting

[1] Abstract from a paper by P. N. Nunn, The Development of the Ontario Power Company. *Am. Inst. E. E.*, Ashville, N. C., June 19–23, 1905.

curtain wall of the outer forebay is made of reinforced concrete faced with wooden planking (see Fig. 3). The water here is 15 feet deep; as the curtain wall extends 9 feet into the water, only deep water is admitted to the forebay, and all floating material is deflected. The water, after entering the outer forebay, passes through a rack into the inner forebay.

The rack structure is 320 feet long and lies across the entrance of the inner forebay, practically parallel with the flow in the outer forebay. All finer floating material which passes the outer deflecting wall is deflected by the main screen house and carried over the spillway (see Fig. 4). At the foot of the rack is a trench or sand-

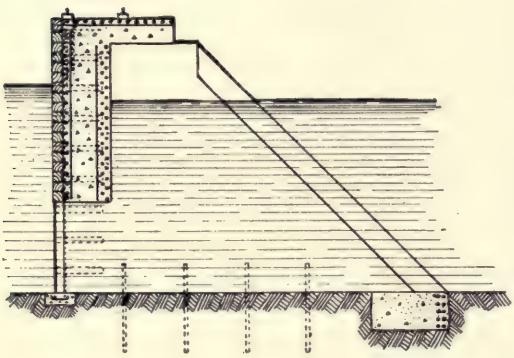


FIG. 3.—Section through Intake of Forebay, Ontario Power Company.

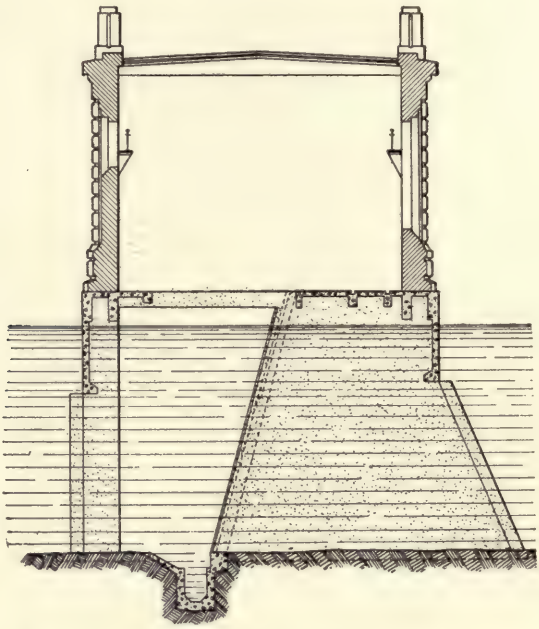


FIG. 4.—Section through Screen House, Ontario Power Company.

trap to carry off sand, gravel, etc. The water at the screen house is 20 feet deep, while at the gate house it is 30 feet deep. The gate house is provided to accommodate three penstocks, with motor-operated head gates. In front of the head gates are wide mesh screens and a curtain wall, extending about 3 feet into the water, to prevent foreign material from entering the penstock. The screen and gate houses are well provided with steam for heating and thawing, also electrically operated cranes to facilitate the changing of screens. As the buildings are located in the reservation, special attention has been paid to the architectural features of same.

Penstocks. The main penstocks are three, of which two are installed; are 18 feet in diameter and laid in the top of the lower cliff. This penstock is made of 0.5-inch material, reinforced on the upper half with bulb tees and covered with concrete (see Fig. 6). It is 6500 feet long and calculated for a velocity of 15 feet per second.

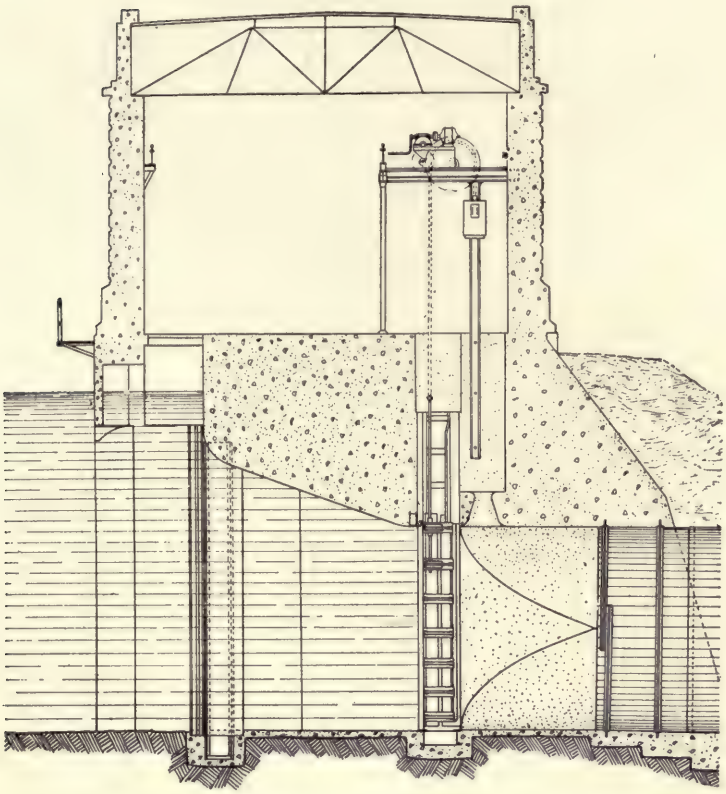


FIG. 5.—Section through Gate House, Ontario Power Company.



FIG. 6.—18-foot Penstock, partly embedded in Concrete, Ontario Power Company.

At the end of the penstock above the power house, cut in the rock, is the valve chamber, from whence seven branches, 9 feet in diameter, lead down to the turbine room, supplying water at a velocity of 10 feet per second. The main penstock also has two 30-inch branches for supplying the exciter turbines. These branches are provided with electrically operated gate valves controlled from the generating room, and run vertically, then horizontally, to the turbines. At the bend they are securely anchored, being embedded in concrete. Each branch is provided with two expansion joints. At the end of the main penstock is a spillway, with a helical discharge. The function of the spillway is to act as a relief valve, in case a generator dropped its load. The characteristic features of the spillway are, the adjustable weir and helical discharge, which preserves a smooth, unbroken water column, with highest velocity and least expenditure of energy. This scheme has been adopted to prevent erosion, restricted flow and excessive air suction, the latter on account of the formation of ice from spray under forced circulation of air.

Power House. The power house is located at the bottom of the cliff, and is 76 feet wide with an ultimate length of 1000 feet. The main turbines are arranged in a single row, and the exciter turbines are set in recesses (see plan and cross section). The cross section is taken through the extreme width, including the recesses.

The whole building, including the roof, is made of concrete and reinforced concrete. It is of handsome design, both exterior and interior. The walls of the latter are faced with white enameled brick. The turbine room is served by a 50-ton, electrically operated crane.

Turbines. The power plant is designed to accommodate twenty-two turbines; at present there are six installed. They are of the horizontal Francis type; two turbines are opposed and mounted on the same shaft. Each has its own feeder penstock and discharges into a common draft tube, 10 feet in diameter. The runner is of cast steel and 78 inches in diameter. The housing is of structural steel, rectangular in plan and spiral in elevation, and 16 feet in diameter. These turbines operate under a head of 175 feet, 20 feet of which is secured in the draft tube, and develop at a speed of 187.5 R.P.M., 12,000 HP. They were designed and built by J. M. Voith, Heidenheim, Germany. The speed of each turbine is controlled by a Lombard governor, located on the mezzanine floor, and are motor controlled, for synchronizing, from the control room. At the end of the penstock branches to the turbines, provision is made for drainage; also hydraulically operated relief valves are installed.

Generators. The generators, of Westinghouse make, are rigidly coupled to the driving shaft. They are of the three-phase type, 25-cycle, 12,000-volt, capable to develop at normal speed, 8000 K.W. The total weight of a generator is 231 tons.

Exciters. The exciters are located on the mezzanine floor; two are at present installed. Each has a capacity of 500 HP., furnishing current at 250 volts. Each is coupled to its own turbine of the Francis type, fed by 30-inch penstocks.

Generator Auxiliaries. There is a separate distributing station, in which is located the bulk of the switching gear. At the operating gallery in the power house is located in groups of six, 12,000-volt oil switches controlling the output of each generator. Here are also located the field rheostats, of which there are at present six installed.

A.E.&
333
UNIV.

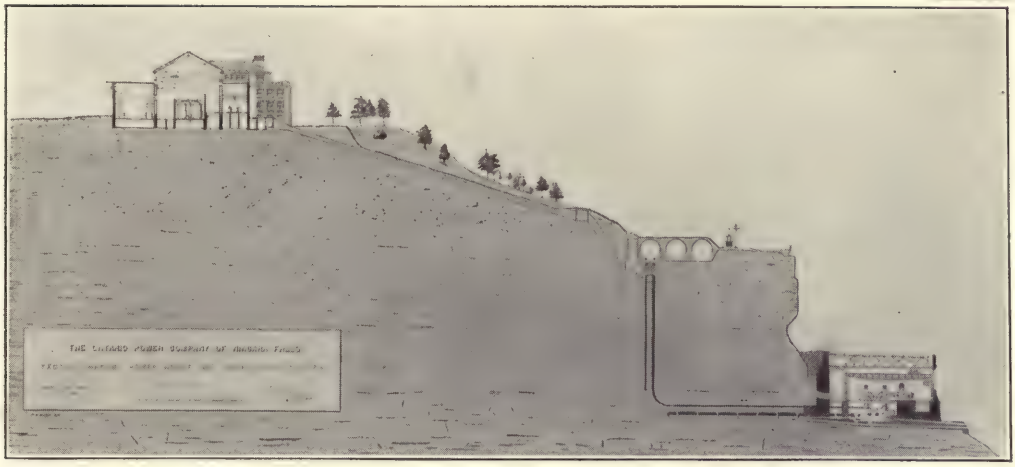


FIG. 7.—Relative Location of Penstocks, Power Plant and Distributing Station, Ontario Power Company.

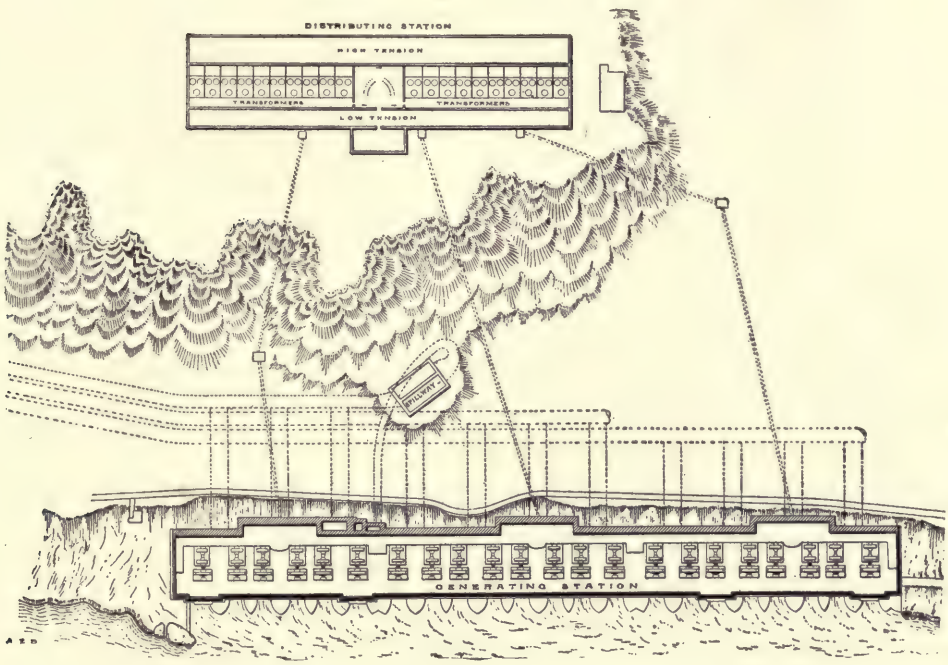


FIG. 8.—Plan of Power Plant and Distributing Station, Ontario Power Company.

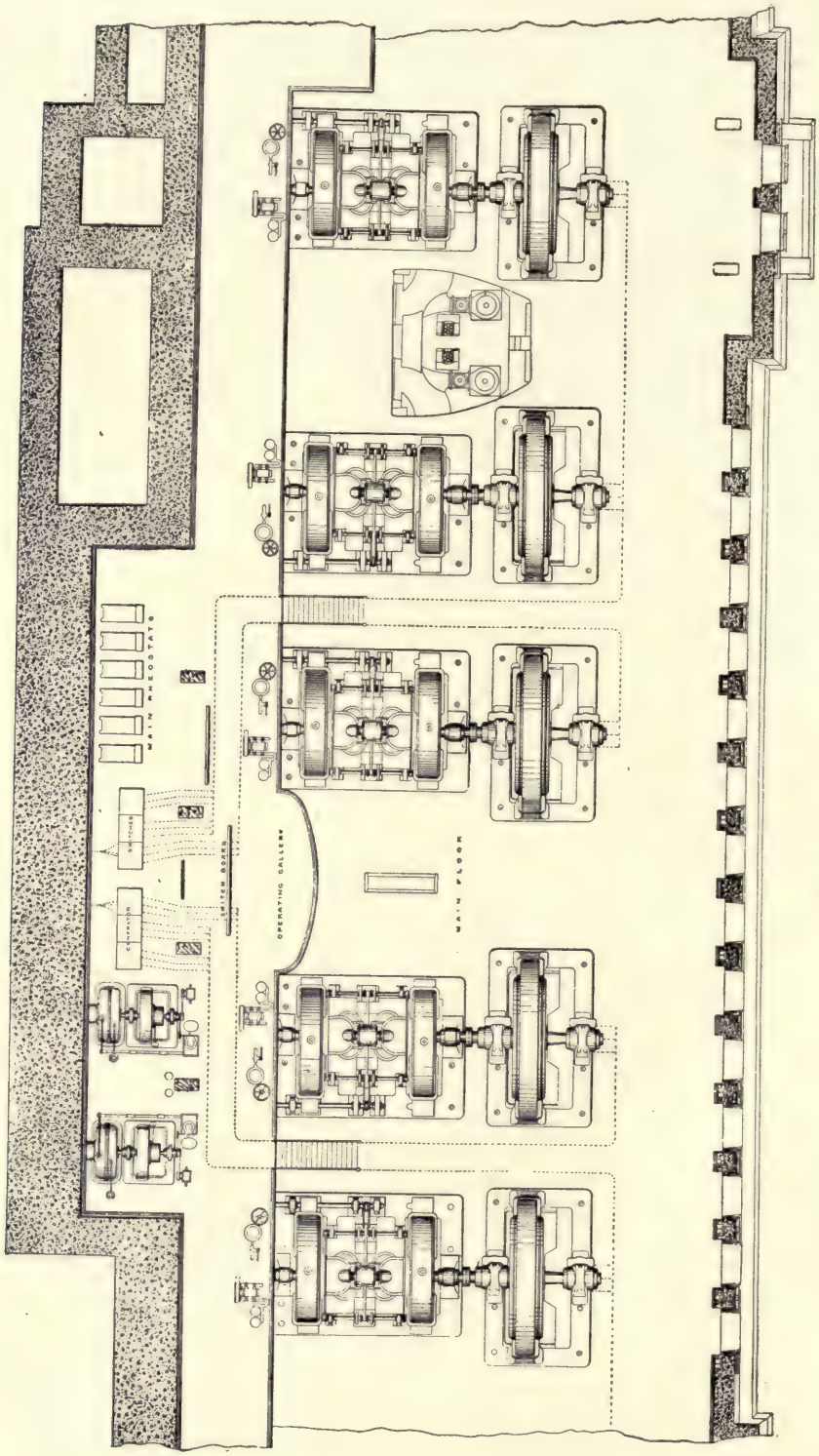


FIG. 9.—Plan of Power Plant, Units 2 to 6, Ontario Power Company.

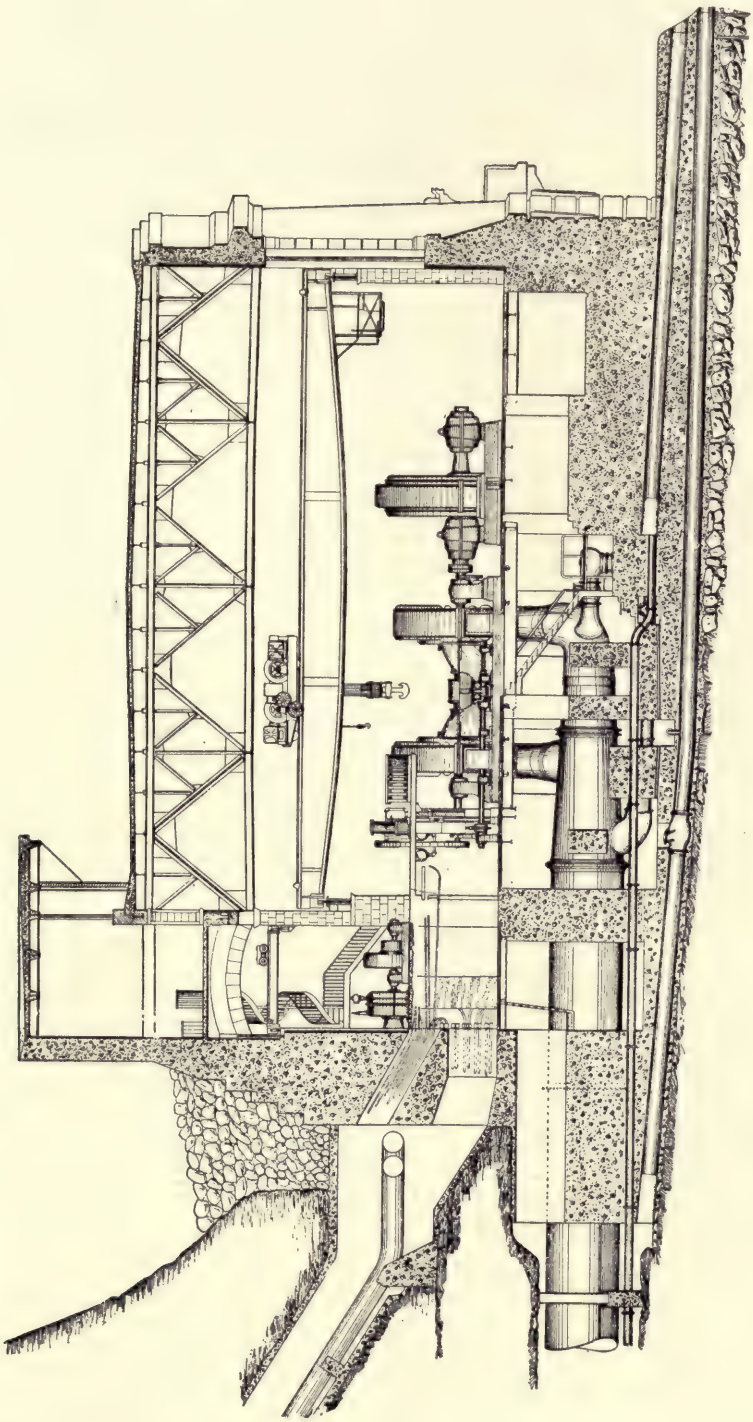


FIG. 10.—Section through Power Plant, Ontario Power Company.

In front of the oil switches on the operating gallery is located a switchboard, having a panel for each generator, upon which are mounted an electrically operated field circuit breaker, an ammeter and control switch for tripping the first generator oil switch. This switchboard also contains two panels, one for each exciter, upon which are mounted the customary switches, a voltmeter and ammeter. Alongside of the exciter board is a panelboard, having the necessary switches for controlling the distribution of alternating and direct current, for lighting and power service in the power house, also for controlling the penstock valves in the valve chamber.

Back of the exciter board are panels, one for two generators, upon which are mounted the terminals of the control wires and relays for the automatic operation of the generators. Under ordinary conditions, the operator has to attend to the exciter current only; and only in case of emergency, does he attend to the generator and field switches.

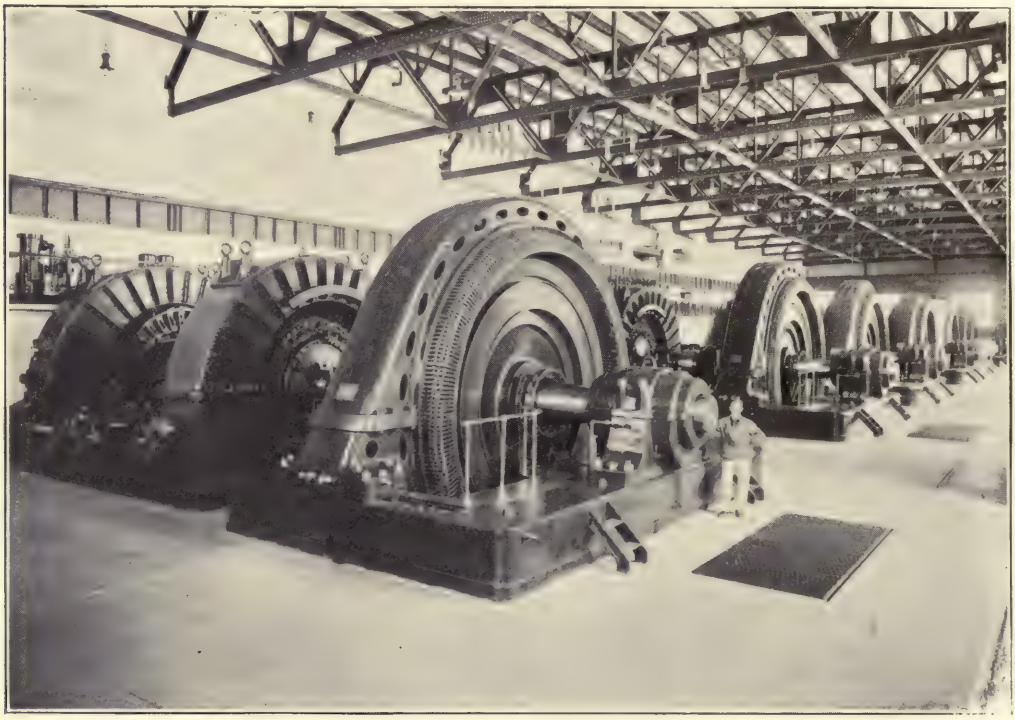


FIG. 11.—Interior of Ontario Power Plant.

Generator Leads. The leads from the generators are single conductors; they are insulated with threaded cambric, mounted upon insulators, each in a separate compartment, made up of thin reinforced concrete shelves. Field circuits, exciter leads and control wires are carried in iron conduits. From the oil switches in the generating room to bell-manholes in the distributing station, the generator leads are of the three-conductor type and in duplicate. They are led through a tunnel

9 feet square and having an incline of 30 degrees, in which are also located the exciter turbine penstocks. After passing under the main penstock, the generator leads are run to a manhole located midway between the power house and the distributing

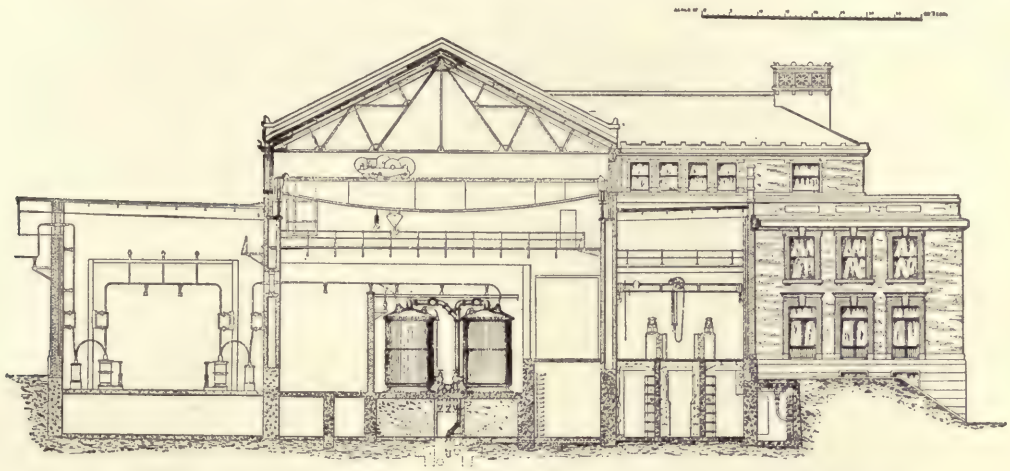


FIG. 12.—Section through Distributing Station, Ontario Power Company.



FIG. 13.—Control Room, Ontario Power Company.

station. From this manhole the cables run through tile ducts. The cables are paper insulated, lead covered, over which is a spirally wound ribbon covered with jute. Special precaution has been taken to see that all cables are well isolated and so located that they may be easily inspected.

Distributing Station.[1] The distributing station is situated on a hill above the cliff and is about 260 feet above the generating station. It is about 500 feet long and 125 feet wide, with a central wing for offices, etc., and designed to accommodate twenty transformer groups. The present installation is built to accommodate six groups.

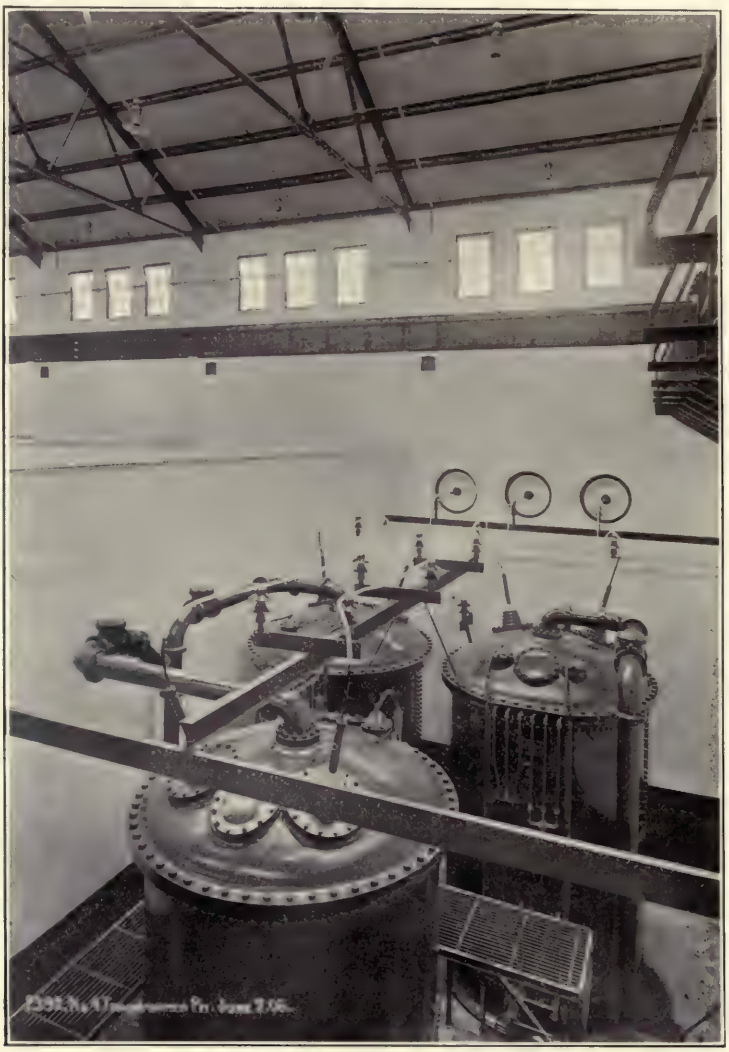


FIG. 14.—Transformer Compartment, Ontario Power Company.

As will be seen in the accompanying illustration, the distributing station is divided into high and low tension bays, between which is located the transformer room separated by partition walls. In the middle of the transformer room and isolated by partition walls, is located the control room. Unlike the power house, which has

[1] Abstract from a paper by V. G. Converse, The Electrical Plant of the Ontario Power Company. *Canadian Electrical Association*, Niagara Falls, June 19–21, 1906.

been begun at one end, the distributing station has been begun in the middle, because it was thought to be more economical in space, and also due to the symmetrical arrangement of the station.

Wiring System. The accompanying diagram clearly illustrates the general layout of the wiring system. It will be seen that the generators may feed either of the two bus-bar systems, or may go directly to the transformers. Low-tension outgoing feeders may be thrown on either of the busses. Sufficient oil switches are provided to give the most flexible system of switching. On both sides of each oil switch are disconnecting switches, to facilitate inspection. All switches feeding busses, both high and low tension, are equipped with overload and reverse current relays, while switches drawing current from the busses have overload and time limit relays. The switches in the generating room can be opened and closed from the control room.

Low-Tension Room. The generator leads entering the low-voltage bus-bar room are single-conductor cables, placed in compartments made up of reinforced concrete. The low-tension switches are arranged in two parallel rows and separated in groups, each comprising a unit. They are of the Westinghouse solenoid plunger type.

Transformer Room. The transformers are located three in a compartment. They are of the Westinghouse water-cooled oil type. Each has a capacity of 3000 K.V.A. and weighs, when filled with oil, approximately 50 tons. They are wound in delta on the low-tension and star on the high-tension side with center grounded. The secondary potential of each transformer is 36,000 volts, and as connected, the resultant line voltage is approximately 62,000 volts. On the low-tension side of the transformer compartments is a track space, providing facilities for assembling and repairs. On the high-tension side of the transformer pit, separated by a low wall, are located choke coils. The transformer room is served by an electrically operated crane for handling transformers and choke coils. The oil and water piping is located between the foundations of the transformers. As will be seen in Fig. 15, the cables which are insulated with cambric and covered with a coating of asbestos, leave the transformer room through insulating bushings, set in circular panels in the division walls between the transformer room and high-tension room.

High-Tension Room. In the high-tension room, the series transformers and oil switches are located on the floor, while the busses, made up of copper pipes wrapped with threaded cambric and asbestos braid, are mounted six feet apart on the top of high walls which separate the units and are well provided with disconnecting switches. The high-tension switches are built on the same plan as the low-tension, but are larger, because of their longer break and greater insulating distance. The oil tanks are of steel and have a capacity of 500 gallons each. Oil pipes and control wires for actuating the switches are carried beneath the floor. In every other compartment are series transformers and oil switches for feeder circuits. The outgoing feeders pass through insulating bushings carried in double glass panels set in the wall near the ceiling. On the outside of the wall they are protected by an overhanging hood. A portion of the high-tension room is reserved for outgoing low-tension (12,000-volt) feeders, their auxiliaries, and also for the service busses.

Control Room. On the top floor of the middle section of the distributing station is the control room; directly underneath on a mezzanine floor are the recording instrument boards, and on the floor beneath are terminal boards. On the floor of the control room are located in a semicircle the control pedestals, and directly behind them are placed the instrument columns. The semicircle is broken in the middle to permit the placing of the feeder control panel. In the center of the room, overlooking all the instruments, is located the desk of the chief operator, from which he can direct his assistants. The control pedestals, one for each generator, contain the following instruments: switches for the control of the oil circuit switches, push buttons for opening and closing generator field switch, controller for the field rheostat, and controller

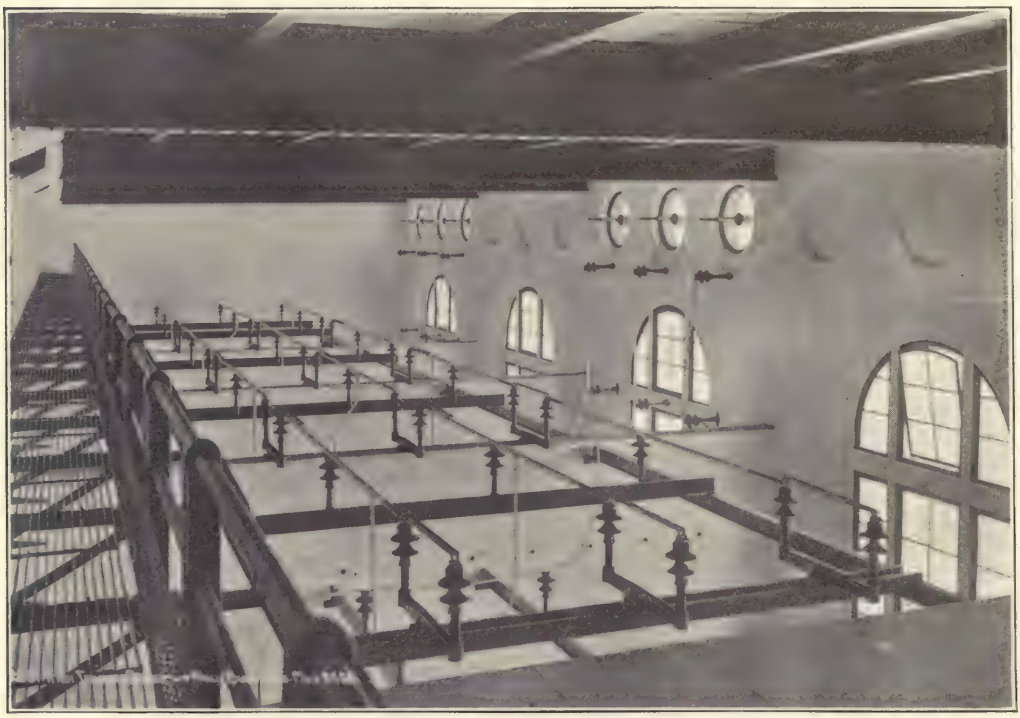


FIG. 15.—High Tension Bus Bars and Outgoing Feeders, Ontario Power Company.

for operating the motor on the turbine governer for synchronizing. Each pedestal has dummy bus bars and signal lamps. Upon each instrument column are mounted a voltmeter, wattmeter, ammeter, power factor indicator, frequency meter, a synchroscope and three ammeters connected to the leads of the transformers. Upon each feeder control panel are mounted the switches and pilot lamps for the control of oil circuit breakers in the duplicate feeders, and three ammeters for feeder circuits. On either side of the entrance to the control room, opposite the semicircle are two service boards, one of which contains the switches and instruments required for the distribution of 220-volt alternating current for light and power purposes in the building. This board also contains the switches for operating the oil switches, located in the

12,000-volt service bus. Upon the other board are mounted the switches and instruments for the 250-volt direct current distribution for lighting and control purposes. The direct current is at present obtained from the exciters. On this board is also a panel controlling a storage battery, which acts as an emergency direct current supply. This storage battery, of 240-ampere-hour capacity, is located in the basement, where are also located the assembly racks for control and instrument wires.

Transmission Line.[1] In the charter granted to the Ontario Power Company, as well as the other Canadian Niagara Falls power plants, all power generated must be

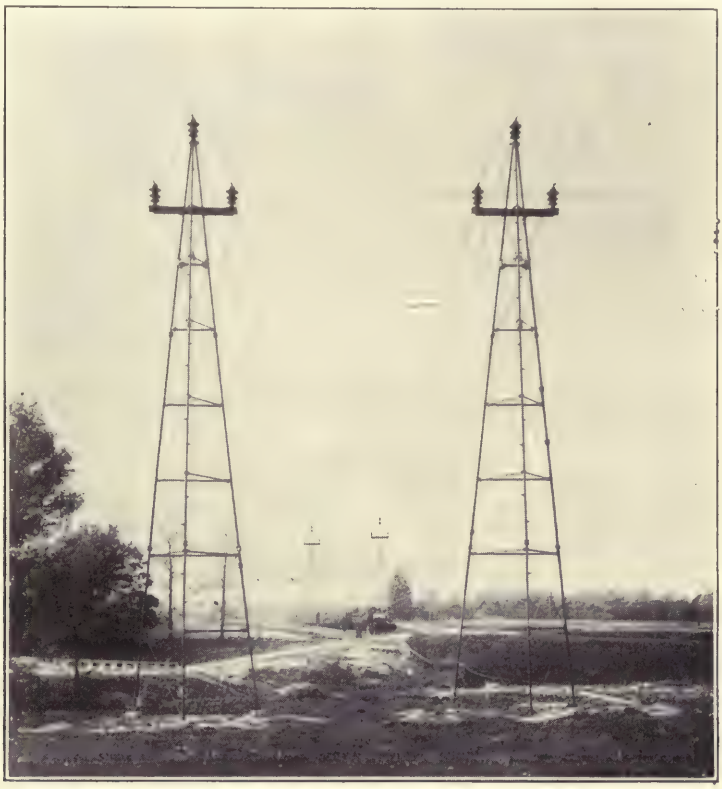


FIG. 16.—62,000-volt Transmission Line near the Distributing Station. Three-Legged Steel-Tube Towers, Ontario Power Company.

transmitted outside of Victoria Park, and that on demand, one-half of the power generated must be supplied to Canadian consumers at the same rate as the consumers on the American side. There is no export or import duty demanded by either government on the transmission of power. As industry on the Canadian side is not developed to a great extent, the bulk of the power is transmitted to the American side, over 160 miles of transmission lines. As the American lines embody many typical features, the following is submitted.

[1] The Transmission Plant of the Niagara, Lockport and Ontario Power Company, by R. D. Mershon, *Am. Inst. E. E.*, September, 1907.

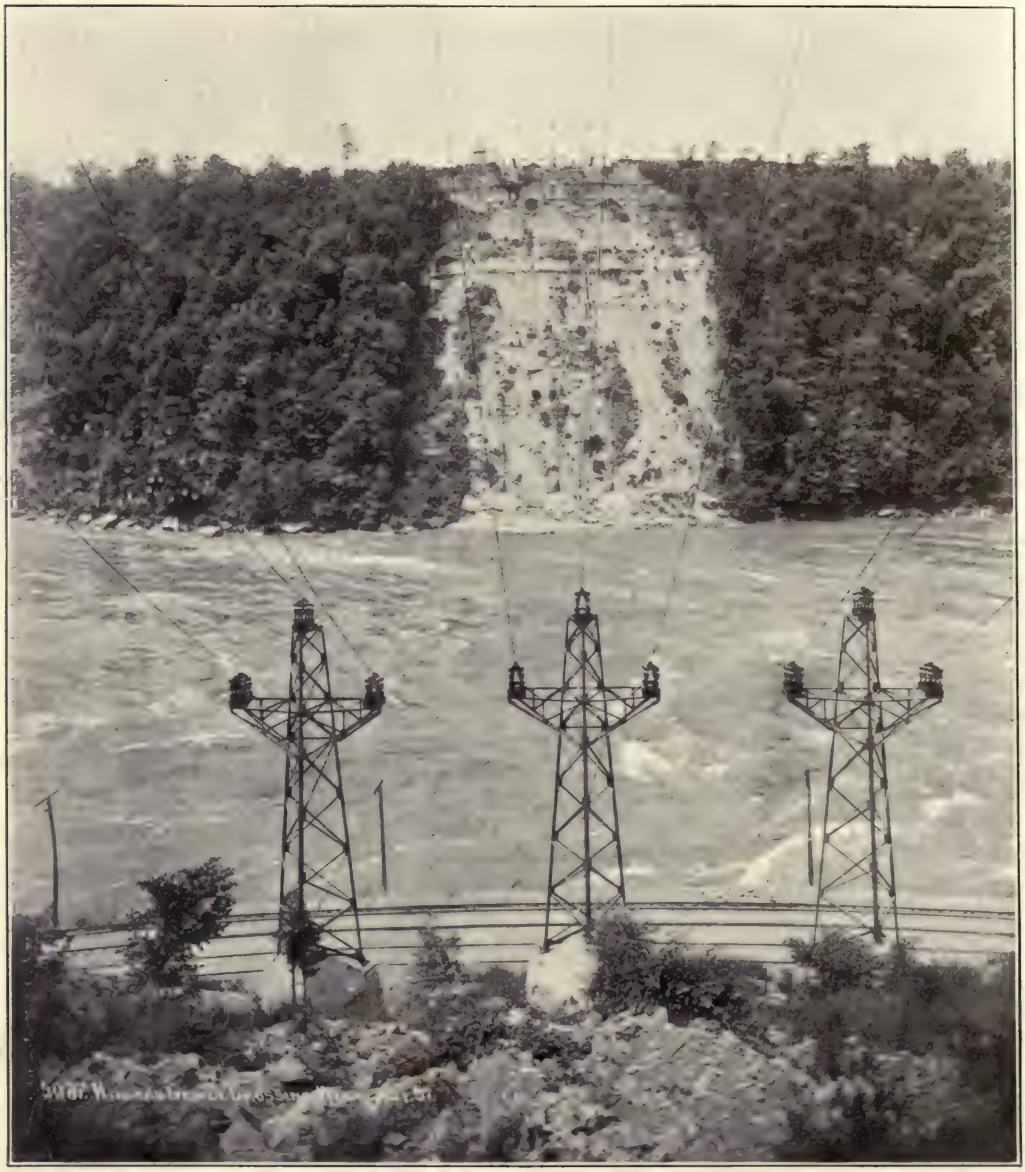


FIG. 17.—Niagara Crossing, General View.



FIG. 18.—Niagara Crossing Cantilever, American Side.



FIG. 19.—Cross Connecting and Disconnecting Switches and Open Air Fuses at Point of Junction of Auburn Branch Line and the Main Line. Niagara, Lockport and Ontario Power Company's Line.

From the distributing station a line of steel towers extends northward, a distance back from the river to a point four miles down the gorge, where the lines cross the latter. Here the lines drop to cantilever arms projecting over the edge of the bank, thence to steel towers erected on the Canadian shore of the river. From here, they cross the gorge with a span of 600 feet to the American side, where similar towers are

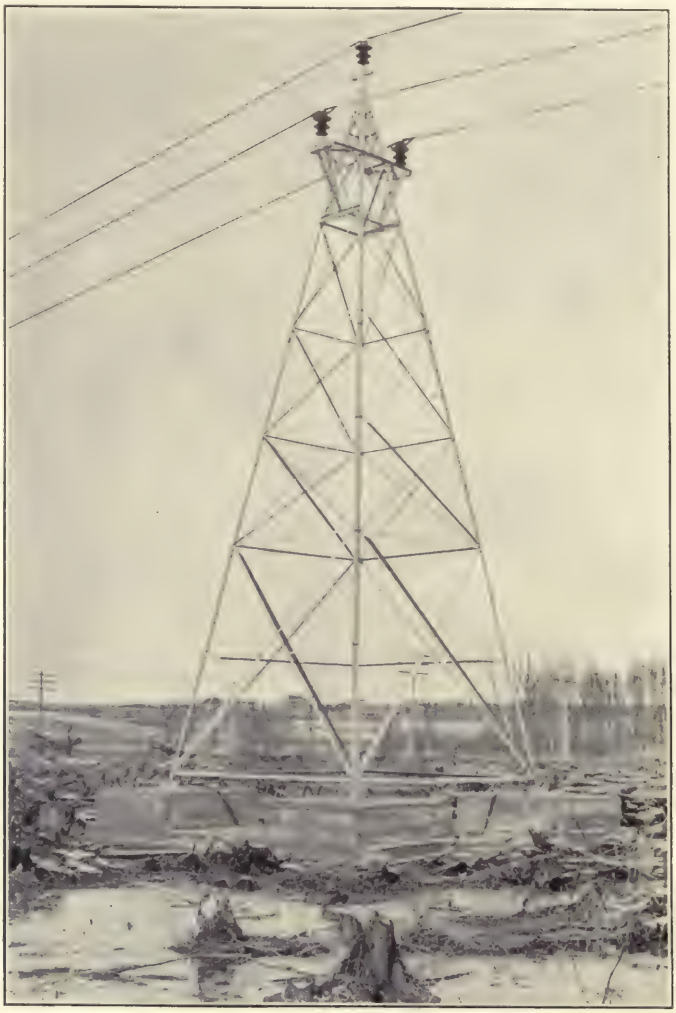


FIG. 20.—Four-Legged Tower on "Floating" Foundation, Montezuma Swamp. Niagara, Lockport and Ontario Power Company's Line.

erected, thence to the cantilevers and the switch house on the American side. Duplicate lines lead to Lockport, 16 miles east, each capable of transmitting 30,000 HP. From Lockport to Mortimer, 57 miles, each line is designed to transmit 20,000 HP. From Mortimer to Syracuse, 81 miles, each line is capable of transmitting 10,000 HP. From Lockport to a point 11 miles east, thence south, to the West Shore Railroad,

thence to Pittsford, is a line of 20,000 HP. From Pittsford, along the West Shore Railroad, to Syracuse, is a line of 10,000 HP. From Lockport to a point south of Buffalo are two transmission lines, each having a capacity of 30,000 HP. The major part of the lines run on private right of way, varying from 75 to 300 feet in width. The transmission towers, with the exception of that portion of the main line on the West Shore Railroad, between Churchville and Syracuse, composed of wooden A-frame structures, are of structural steel, spaced 500 feet apart as standard. In some portions of the line the spans are longer, the longest being 1253 feet, which, of course, requires higher and special designed towers. The first towers installed are of the three-legged type, made up of steel tubes, while the bulk are of structural steel, heavily galvanized. Of this latter there are two types, the guyed and unguyed; the former are provided with guys and double sets of insulators. The guyed towers are placed at intervals, anchored in both directions of the line. Their duty is to meet the contingency of all three cables breaking on one side of the tower. The towers are set in reinforced concrete foundations with a broad base to utilize the weight of the earth around them in resisting uplift. The towers and their foundations are capable of withstanding the transverse force which will be brought upon them when covered with 15 inches of ice all around and the wind blowing transversely to the line at 75 miles per hour. The towers are shipped knocked down and assembled in the field. They are erected by means of a field derrick and a team of horses. The insulators on the main line are 14.5 inches diameter, three-petticoat type. The three parts are cemented together and the whole mounted on a cast steel pin, bolted by three bolts to the structure of the tower. The total height of these insulators is 19 inches. The insulators on the branch lines are of less expensive design. Each branch has, where it is tapped on the main line, 60,000 volt outdoor fuses, consisting of thin copper wire 16 feet long, incased in a rubber tube, mounted on wooden bars, supported by line insulators and mounted on a pole. Three sizes of cable are employed and designated as 3/3, 2/3, 1/3. The 3/3 cable is of aluminum, and consists of 19 strands, having a total area of 642,800 circular mils, being equivalent to 400,000 circular mils of copper. The cross-section area of the others is 2/3 and 1/3 respectively of the 3/3. The cables are held in place on the insulators by aluminum tie wires. All joints are of the twisted sleeve type. At intervals along the line are placed disconnecting switches to cut out sections when necessary. Some of the disconnecting switches are arranged as cross-connecting switches. At intervals along the line are located patrol houses, for storage purposes and accommodating patrolmen. The accommodations consist of kitchen, sleeping and sitting room. A private telephone line runs the entire length of the system on wooden poles. Stationary and portable telephones are provided.

Substations.[1] There are at present installed along the line three substations, at Lockport, Gardenville and Baldwinsville, respectively. The two former have each at present a normal capacity of 3000 K.W. and are designed for additional increase. The latter has a capacity of 750 K.W. The bus bar system of the substation is out of doors, i.e., the bus bars have been treated as though they were a part of the transmission line, and are located outdoors. In connection with same are disconnecting

[1] See *Electrical World*, May 2, 1908.

switches for making various connections of apparatus. Disconnecting switches are not intended to break the working current. When it is necessary to break the circuit under load, it will be done by high tension oil switches, connected in the substations



FIG. 21.—Lockport Substation, showing Outdoor 60,000-volt Bus Bars.

In a similar way are located the horn type lightning arresters. Each phase is provided with three lightning arresters set with gaps of different lengths. One is set for low striking distance, and has in series with it a high resistance; the next is set for higher striking E.M.F., and has in series a low resistance; the third pair is

set for very high striking force and has a fuse in series. Slight static discharges are relieved by the lowest set arrester, a higher discharge by two lowest, and in extreme cases, all three operate.

The equipment of the substations is similar to that found in everyday practice. To provide for a cooling system for the oil transformers, wells had to be sunk and pumping plants installed, also water towers and a cooling pond, the latter to be used in case the wells failed to supply water. A complete oil piping system for the transformers is installed. Private transformer substations are located in Auburn and



FIG. 22.—60,000-volt Circuit Breaker, Lockport Substation.

Syracuse. The station at Auburn supersedes and supplements the steam generating apparatus of the Auburn Light, Heat and Power Company. This company purchases power according to a system of charges based on one-minute peak loads, so that it is advantageous to maintain a high load factor. For this purpose, a certain portion of the steam-driven apparatus has been retained.

In connection with the Syracuse end of the line, the Syracuse Rapid Transit Company has a two-mile 60,000-volt transmission line, leading from the city's western boundary to the substation at Tracy Street, on the bank of the Erie Canal. There are forty specially designed structural steel towers, varying in height, from 45 to 63 feet. Each leg of the three-phase circuit consists of a seven-strand seven-sixteenths plow steel cable. The average span is 240 feet, the longest 497 feet.

THE GREAT FALLS POWER PLANT OF THE SOUTHERN POWER COMPANY, CHARLOTTE, N. C.

The Southern Power Company owns and controls, in all, nine water-power sites in the so-called Piedmont section, embracing the Sand Hill district, extending from the foot of the Blue Ridge Mountains, a distance averaging probably 120 miles. One water power with a capacity of 12,000 HP., lies on the Broad River of the Carolinas, equidistant from Gaffney and Blacksburg, S. C., while the other is located on the Wateree River, of which the Catawba River is the principal tributary. This one is capable of developing 20,000 HP. All others are on the Catawba River. The aggregate of these powers amounts to 145,000 HP., which will be transmitted over an area 150 miles long and about 100 miles wide. Of these different water power sites, the one known as the Great Falls of the Catawba was the best for initial development.

Great Falls consists of a series of falls and shoals, having a total head of 176 feet in a distance of eight miles, the development of which will require three separate plants.

The lowest of these necessitates the construction of a dam across the river, at a point just below the mouth of Rocky Creek, having a drainage area of 4450 square miles; a development of 60 feet head is here visible. With the construction of a dam immediately above the mouth of Fishing Creek, 40 feet can be developed; the drainage area will be 3900 square miles.

The middle development, with a head of 72 feet, has a drainage area of 4200 square miles, and is known as the Great Falls station, the subject of this description.[1]

The essential features of this development consist of a low spillway dam at the head of Mountain Island, diverting the water into the western channel; near the foot of the island are the head gates and another spillway dam, as seen in Fig. 1; an extension of this dam serves as an overflow weir between the canal and the river. From this point the stream is carried through a valley 1.25 miles to the power house, where a retaining bulkhead is built across the valley; the tailrace discharges into Rocky Creek.

Spillway. The main spillway at the head works is 438.8 feet long at the crest line, with an average head of 30 feet; it has a batter of 1 : 10 on the upstream face. The width at the base is 41 feet.

The spillway dam in the canal is of similar design, 521.2 feet long on the crest, and 37.75 feet wide at the bottom; the average height is 36 feet. The crest on this weir is one foot higher than the main spillway. It is built up of cyclopean masonry, the concrete being 1 : 2 : 5; the biggest stones are as large as could be handled by the derricks. Sectional forms were used to the greatest practical height, the upper curves being then finished by hand and template.

The inlet to the headrace is provided with ten sets of coarse racks consisting of 5 by three-eighths inch bars on 3-inch centers, each being 16 feet wide, and 18.5 feet

[1] The Great Falls Station of the Southern Power Co., by Curtis A. Mees and John H. Roddey. *The Engineering Record*, May 18, 25, and June 1, 1907.

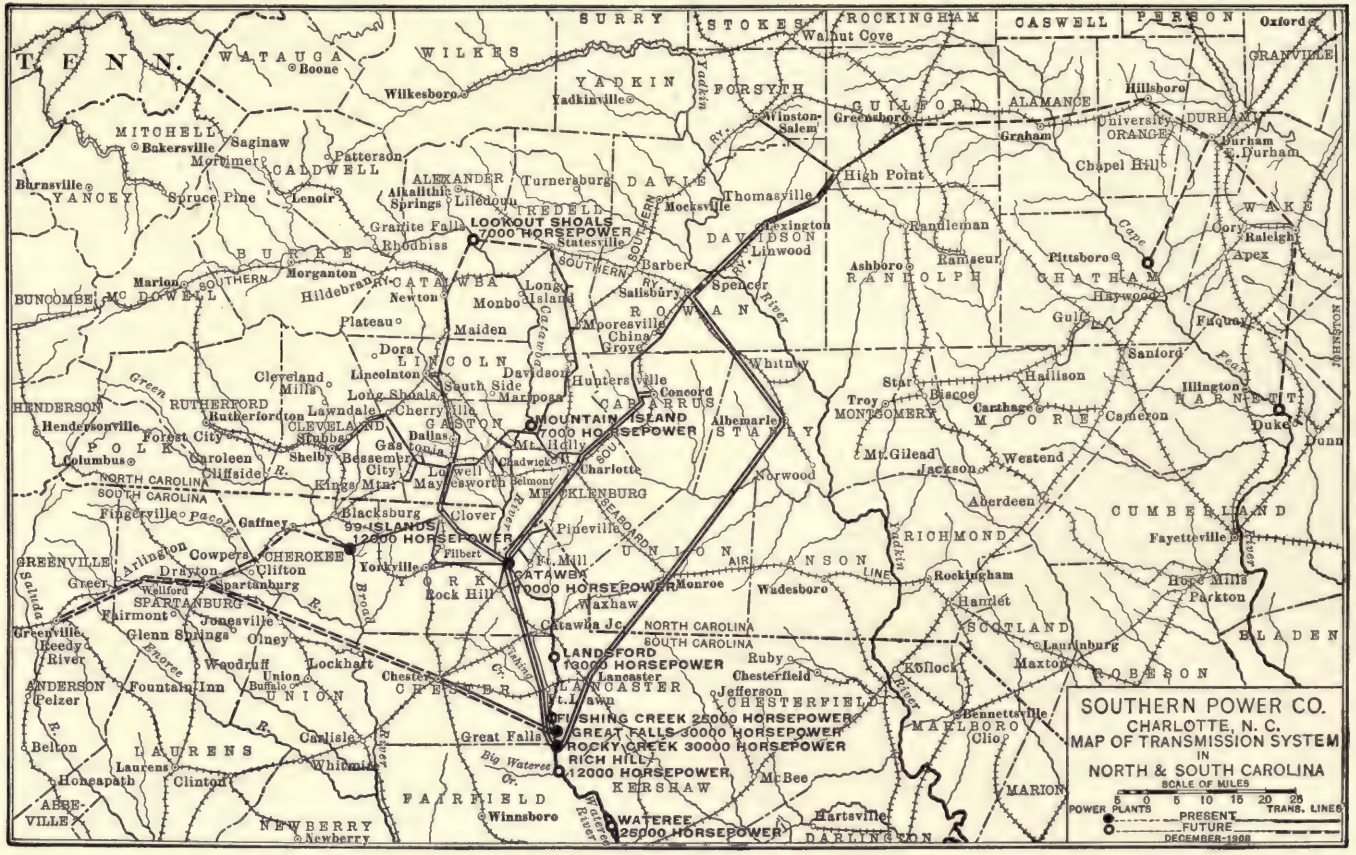


FIG. 1.—Map of Southern Power Company's Transmission System.

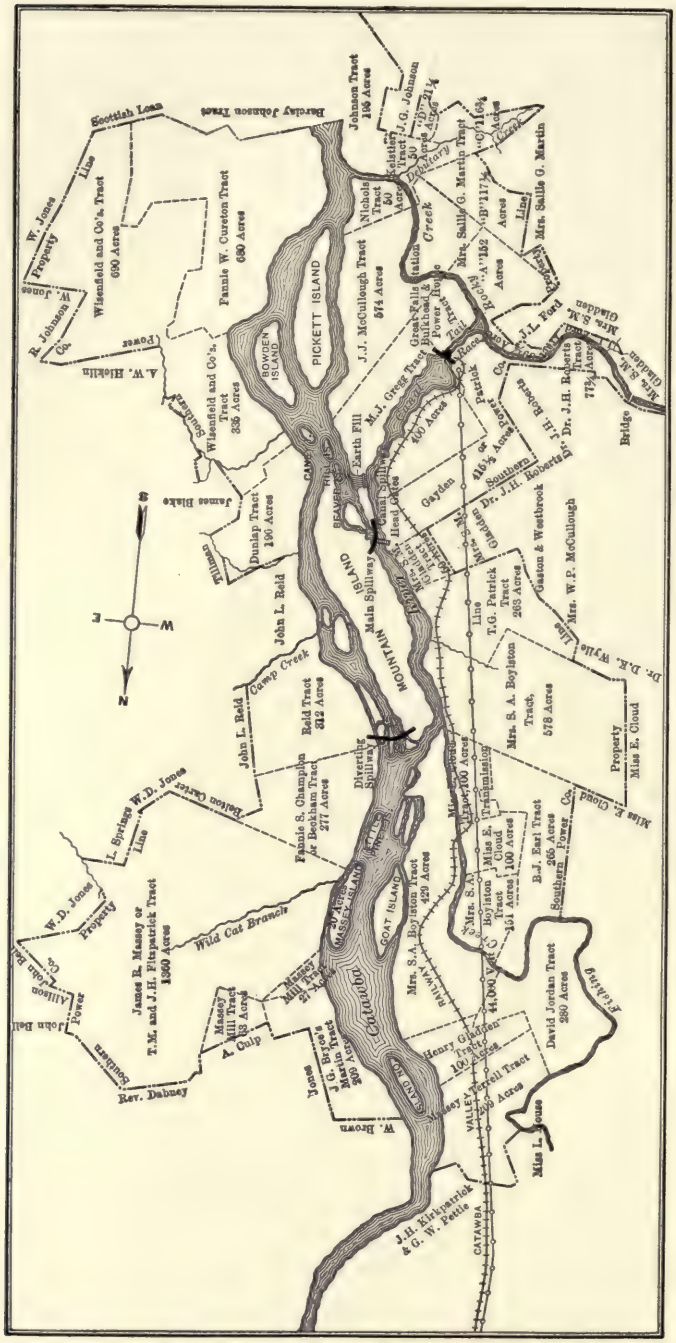


FIG. 2.—General Map of Power Development, Southern Power Company.

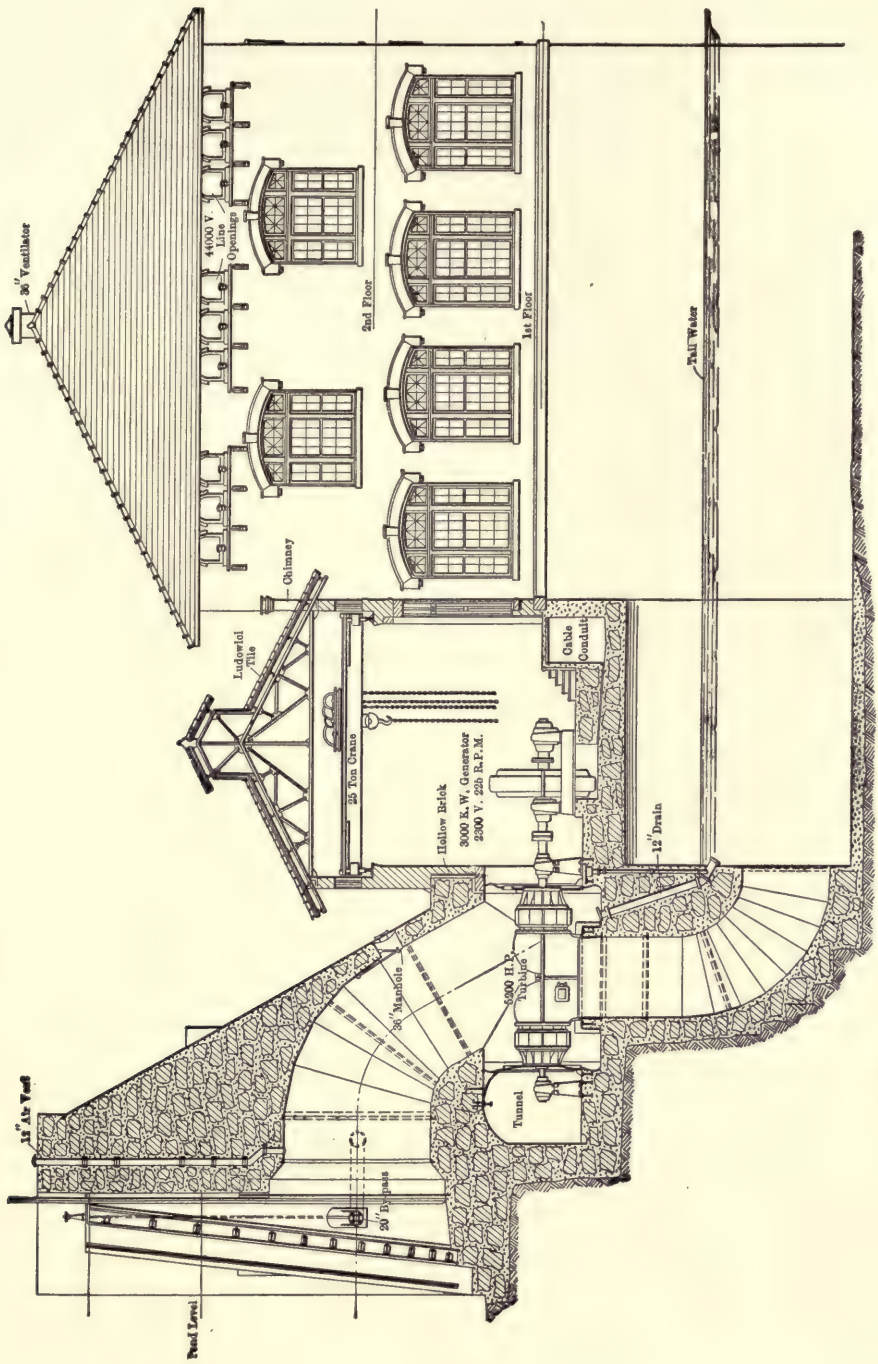


FIG. 3.—Sectional Elevation of Power Plant, Southern Power Company.

high, held by piers 45 feet high, 5 feet across and 8 feet wide at the top, with a 3 : 1 batter downstream, forming a buttress. Piers are also carried out on the upstream side for the support of the structure. These have a batter of 12 : 5, giving the section at the base a total width of 47 feet.

The gate frames are of structural steel and of the same design as those at the penstock inlet, and are provided with by-passes for the purpose of relieving them of pressure before raising. There is a 4 by 5-foot Coffin sluice gate for drainage purposes.

Main Dam. The bulkhead, or main dam, to which the power house is adjoined, has a width at the top of 8 feet; the upstream face is vertical, the downstream face is battered 1.75 : 1. The height in the center of the valley is about 90 feet. The cross section is largely increased in that section opposite the power house, for here are built, through the bulkhead, the intake flumes to the turbines, which are also located in this section; whereas the generator is located in the power house built immediately below the bulkhead, virtually forming a part of it.

At either end of the power house in this wall there are two 48-inch Coffin sluice gates for by-passing leaves and small débris from the racks.

The water, before it enters the turbine intakes, has to pass through screens of 4 by one-fourth-inch grid bars spaced 1.5 inches on centers, and structural steel gates, each of which is provided with two by-pass or filling gates, 9 by 14 inches.

Eight of these gates admitting water to the main turbines are built of 6-inch I-beams covered with three-eighth-inch steel plate on the outer side. On the inner side they have bronze running strips on the guides, while machined bearing plates at top and bottom insure tightness when the gates are closed.

There are two smaller gates constructed of 4-inch I-beams, admitting water to the exciter turbines; each is provided with a filling gate 9 by 12 inches. The exciter gates are operated by hand, while the main gates are operated by means of a motor located in a small house on the top of the bulkhead. The motor receives 250 volts from the exciter units.

Turbines. There are eight main turbo-units 5200 HP. making 225 R.P.M. under a head of 72 feet, and two 700 HP. exciter turbines making 450 R.P.M. Each unit consists of a pair of horizontal twin turbines with top inlet and central discharge. Two of the main units were furnished by the Holyoke Machine Company, the remainder by the Allis-Chalmers Company.

The former have a guaranteed efficiency as follows:

Discharge	Full	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$
Efficiency per cent	81	82	81	74	68

The efficiencies of the latter make are:

Discharge	Full	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{1}{4}$
Efficiency, per cent	80	81	82	80	78	60

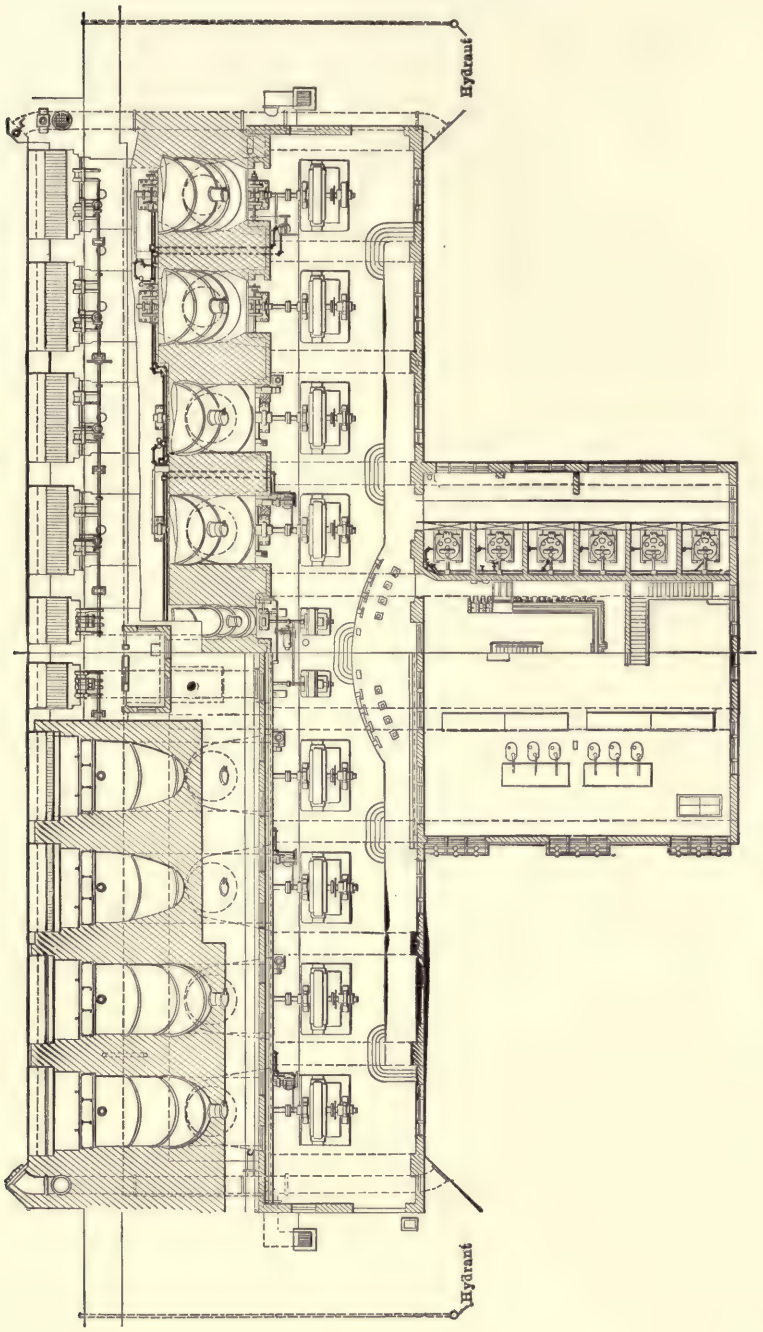


FIG. 4.—Plan of Power Plant, Southern Power Company.

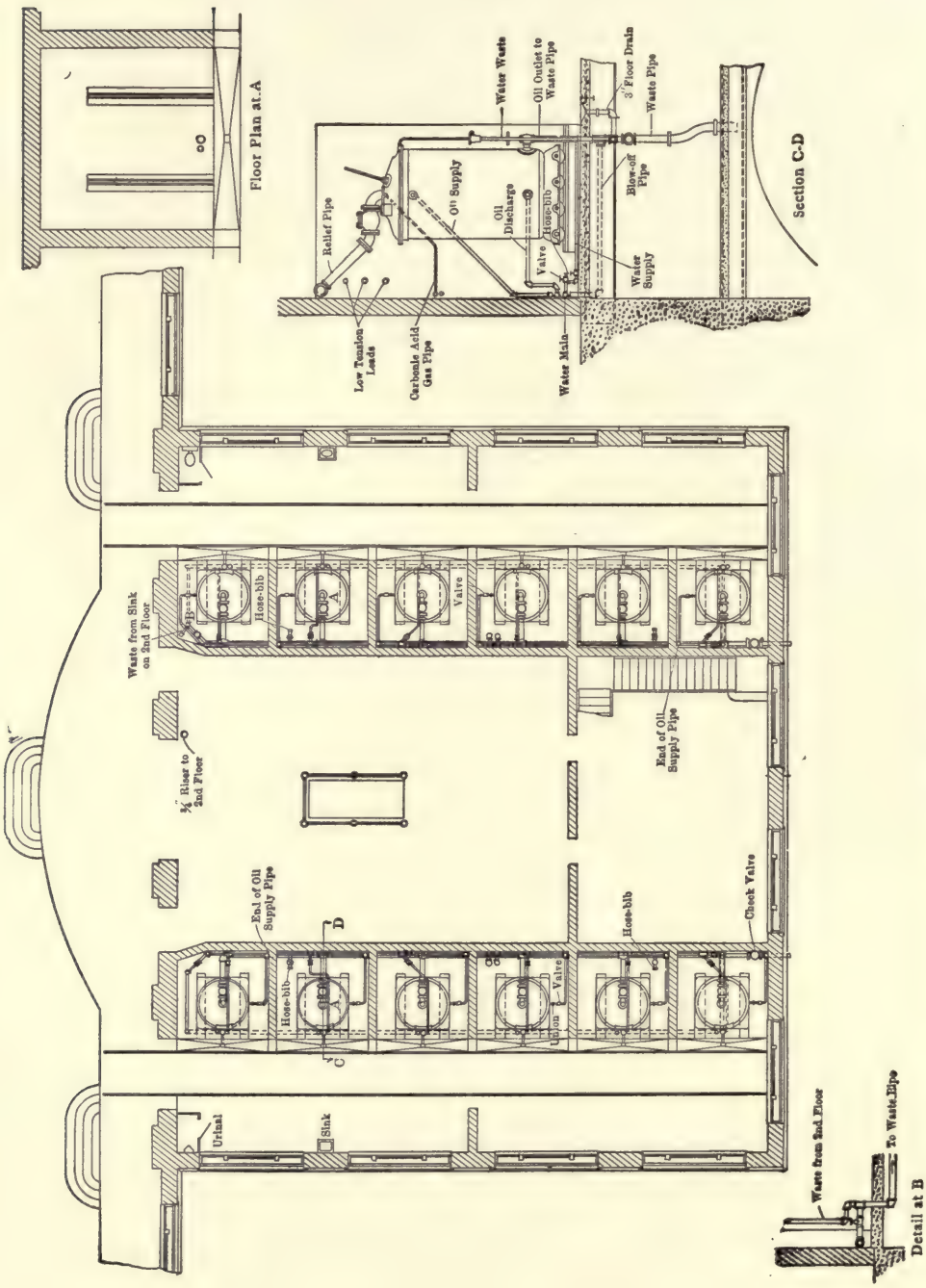


FIG. 5.—Plan of Transformer Room and Transformer Pipe Connections, Southern Power Company.

The runners of the Holyoke turbines are 48 inches in diameter. The runners of the Allis-Chalmers turbines are 53 inches in diameter, and the draft connection 11 feet in diameter, which gradually increases to 18 feet 3 inches, by 11 feet 2 inches. The intake flumes are 18.5 feet by 16 feet, and taper down to 15 feet in diameter at the turbine casing.

The runners of the exciter turbines are 24.5 inches in diameter. The intake of the same is 9 feet high with semicircular ends of 3-foot radius, tapering down to 6 feet in diameter at the turbine casing. The draft tubes are 5 feet 6 inches in diameter at the casing, and flare to a width of 9 feet 10 inches, with semicircular ends of 2 feet 9 inches radius.

As the turbines are located in the body of the dam, a tunnel in the latter is provided, so that access may be had to the outside bearings.

The turbo-generator sets are controlled in pairs by Lombard governors; there is one type "N" governor for two sets of main turbines, while the two exciter units are controlled by a single type "P" governor. The "N" type, developing 31,000 foot-pounds, are guaranteed to completely open and close the gates in 1.5 seconds; while the "P" type, developing 6700 foot-pounds, in 4 seconds. The former are electric controlled from the switchboard.

There are 4 by 6-inch triplex pumps operated by belts from the turbine shafts; these, and the pressure tanks are located in the above mentioned tunnel.

Power House. The power house is 250 feet long and 37 feet wide. Adjoining same is a two-story switch and transformer house 85 feet long and 75 feet wide. The generating room is well provided with 20-inch roof ventilators, and is served by a 25-ton hand crane, with a 5-ton auxiliary trolley.

On the main floor, in the switch and transformer house, are located the low tension oil-switches and transformers, while on the upper floors is the high tension apparatus.

Generators. The main generators are of 3000 K.W. capacity, 60 cycles, 2300 volts. The exciters are 400 K.W. capacity, 250 volts. The guarantee of the main generators is as follows:

Load	Full	¾	½	¼
Efficiency, per cent	96	95.5	94	90

The temperature is guaranteed not to exceed 35° C., after 24 hours run at normal load, and 50° C., at 37.5 per cent overload for the same duration.

The guaranteed efficiencies of the exciters are as follows:

Load	¼	½	¾	Full	1¼
Efficiency, per cent	80	88	91	92	92

Switchboard. As will be noticed in the accompanying illustration, the switchboard is located several feet above the floor on a raised platform. It is made of blue Vermont marble and contains two transformer panels, two double-circuit feeder panels, one station and two blank panels.

In front of the switchboard, arranged in a semicircle, are eight instrument posts and eight pedestals for controlling the main generators. Switchboard, instrument columns, and control pedestals are well equipped according to modern practice.



FIG. 6.—Power House, seen from Tailrace, Southern Power Company.

The generator leads are lead-covered cables, and run through tile ducts laid in the floor.

Wiring Diagram. There are two sets of exciter bus bars and one main generator bus. The generators feed the latter through non-automatic oil circuit breakers; between the transformers and the low tension bus are located overload time limit oil circuit breakers. Between the transformers and the high tension bus (44,000 volts) are reverse current circuit breakers. Both bus bars are divided up into two sections by sectionalizing switches, on both sides of which are disconnecting switches. The outgoing feeders are provided with overload time limit circuit breakers.

The whole wiring diagram is such that two generators can feed, through one transformer, a single transmission circuit, or they may feed any of the transformers or outgoing lines. Again, the transformers may feed directly the outgoing feeders by by-passing the high tension bus bar.

The tow tension bus bar is made up of five strips of 3 by one-fourth inch copper,

A.E.&M
UNIV. OF C



FIG. 7.—Interior of Generating Room, Southern Power Company.

clamped together. These and the low tension oil switches are located in structures built up of concrete slabs and steel framing. The high tension bus consists of 1-inch copper tubes, supported on a steel structure of latticed girders, which also carries the selector switches.

Transformers. The transformers are arranged in four banks of three each. They are of 2000 K.W. capacity oil-insulated, water-cooled, and step up the generator voltage to 44,000. By means of multiple connections, the additional ratios of 550/10,000 and 1100/22,000 volts may be obtained. Provision is also made inside of the transformer tank to secure 1900, 2000, and 2100 volts.

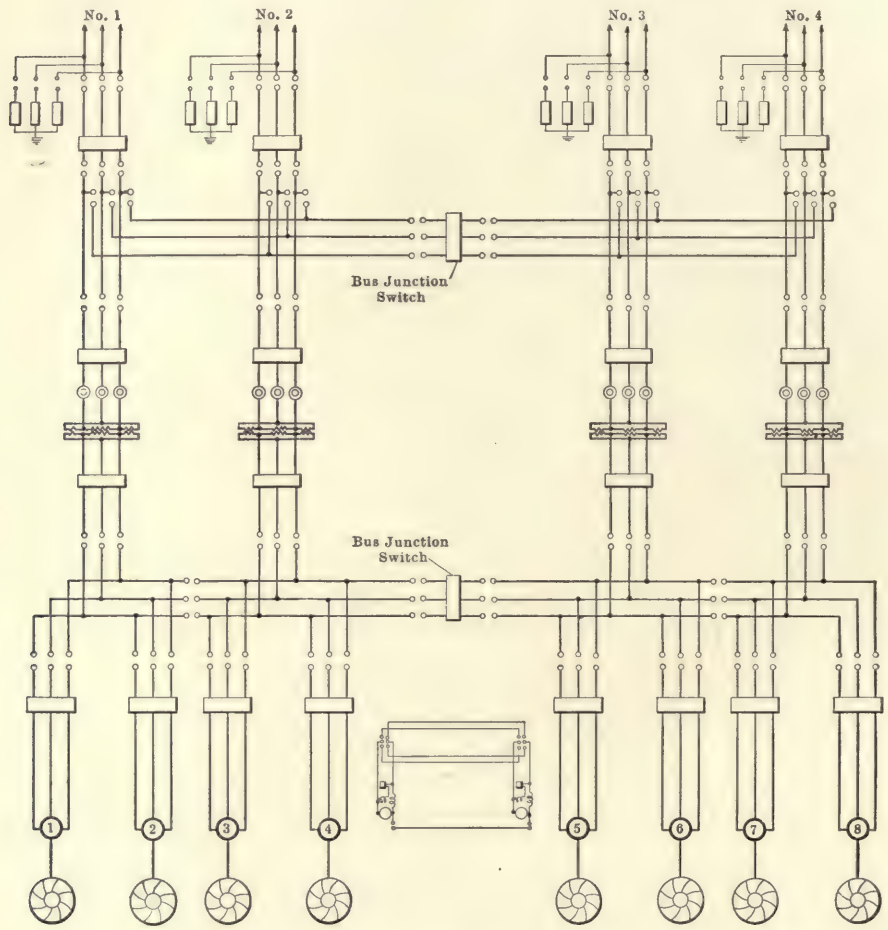


FIG. 8.—Wiring Diagram, Great Falls Plant, Southern Power Company.

With a temperature rise not exceeding 60° C., a circulation of 4 gallons of water per minute at full load is required, while with 5 gallons of water per minute, and 1.25 load, the temperature will not exceed 55° C. over that of the intake water, during continuous operation.

The guarantees are as follows:

Power factor	100	90	85
Regulation, per cent	0.95	2.4	2.9

Load	¼	½	¾	Full	1¼
Efficiency, per cent	96.4	98	98.3	98.4	98.3

The transformers are located in compartments resting upon rollers on rails, in front of which is a transfer table, by which means they may be moved into the generating room where they are handled by the overhead crane.

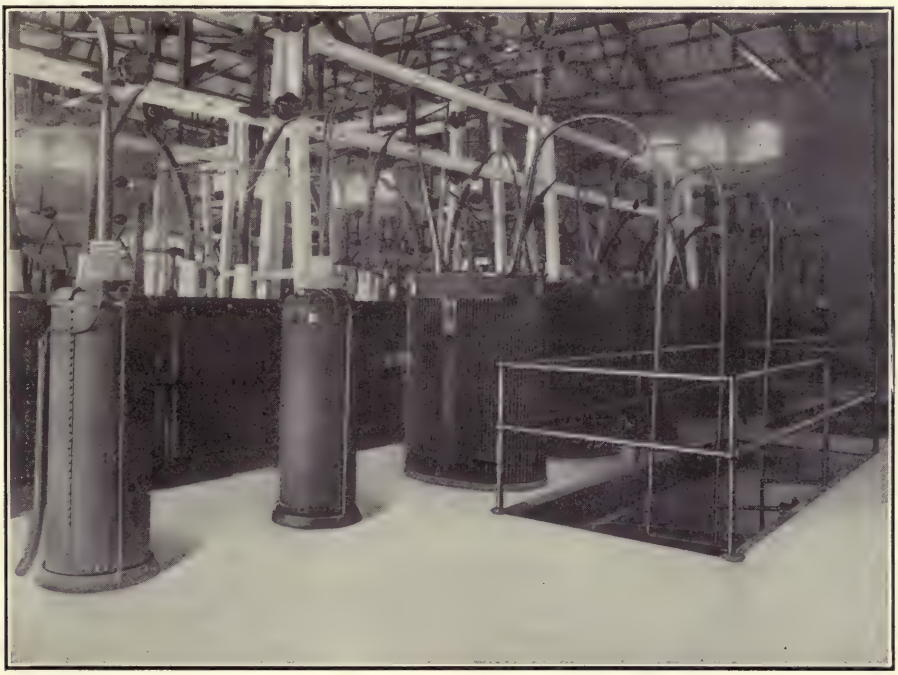


FIG. 9.—High Tension Switch Room, Southern Power Company.

All transformers are connected to a pipe system, by which carbonic acid gas may be admitted in case of fire. The carbonic acid generator and pressure tank are located in the basement of the transformer house. Connections are also made to the upper floor, so that in case of fire, the various apparatus may be attacked by the gas

Oil to the transformers may be supplied by gravity or under pressure, for which purpose an electric operated triplex pump is installed in the basement. The circulating water is obtained by gravity from the exciter turbine supply.

Protection. In order to partially relieve the transformer windings of excessive strain, due to surges in the line, choke coils of the oil-insulated type are placed between the transformers and their respective bus oil switch. The lightning arresters are of the single pole, low equivalent type.

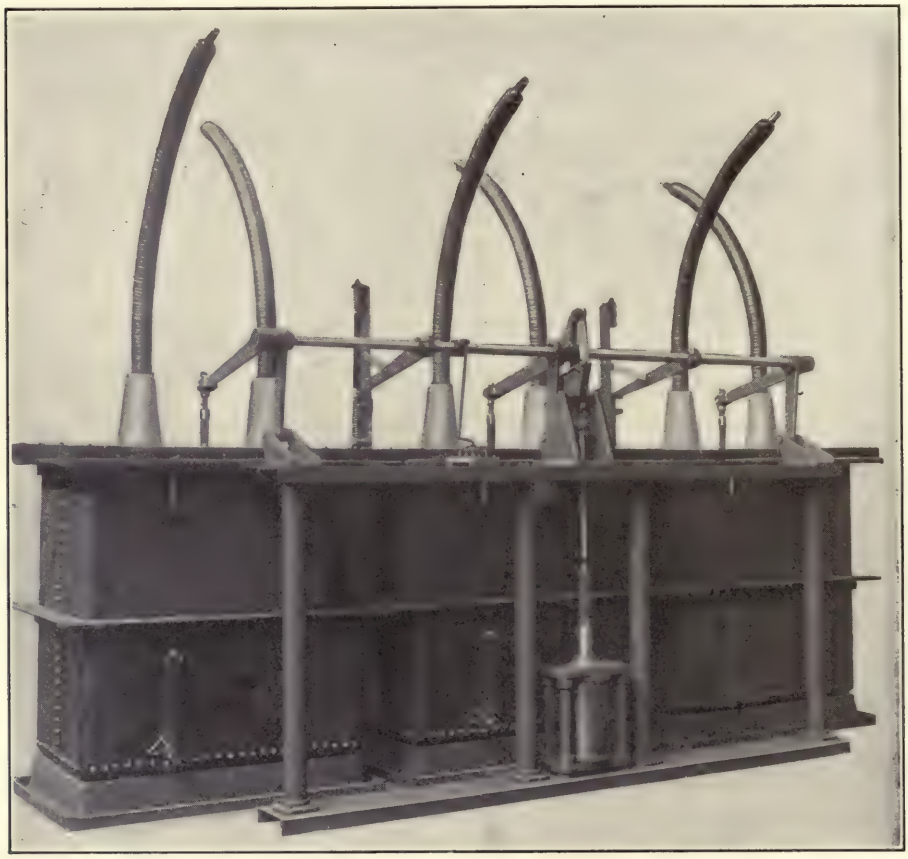


FIG. 10.—Solenoid Operated Oil Switches.

Transmission Lines. Current is transmitted from the Catawba station to near-by towns at 11,000 volts. The poles are 35 feet long, 14 inches at the butt, and 7 inches at the top, and buried 5.5 feet in the ground, this section being thoroughly coated with coal tar. The line running to Rock Hill consists of two circuits of No. 0 hard drawn copper wire. On the line to Charlotte and Fort Mill, aluminum cables of 200,000 cm. are used. The poles on the former are spaced 100 feet, while on the latter, 150 feet apart.

The whole transmission system, with the exception of the Rock Hill, Fort Mill and Yorkville line, is being changed preparatory for transmission at 44,000 volts, immediately upon completion of the Great Falls station. From Great Falls to Catawba station, a trunk line supported on steel towers is being built. At Catawba

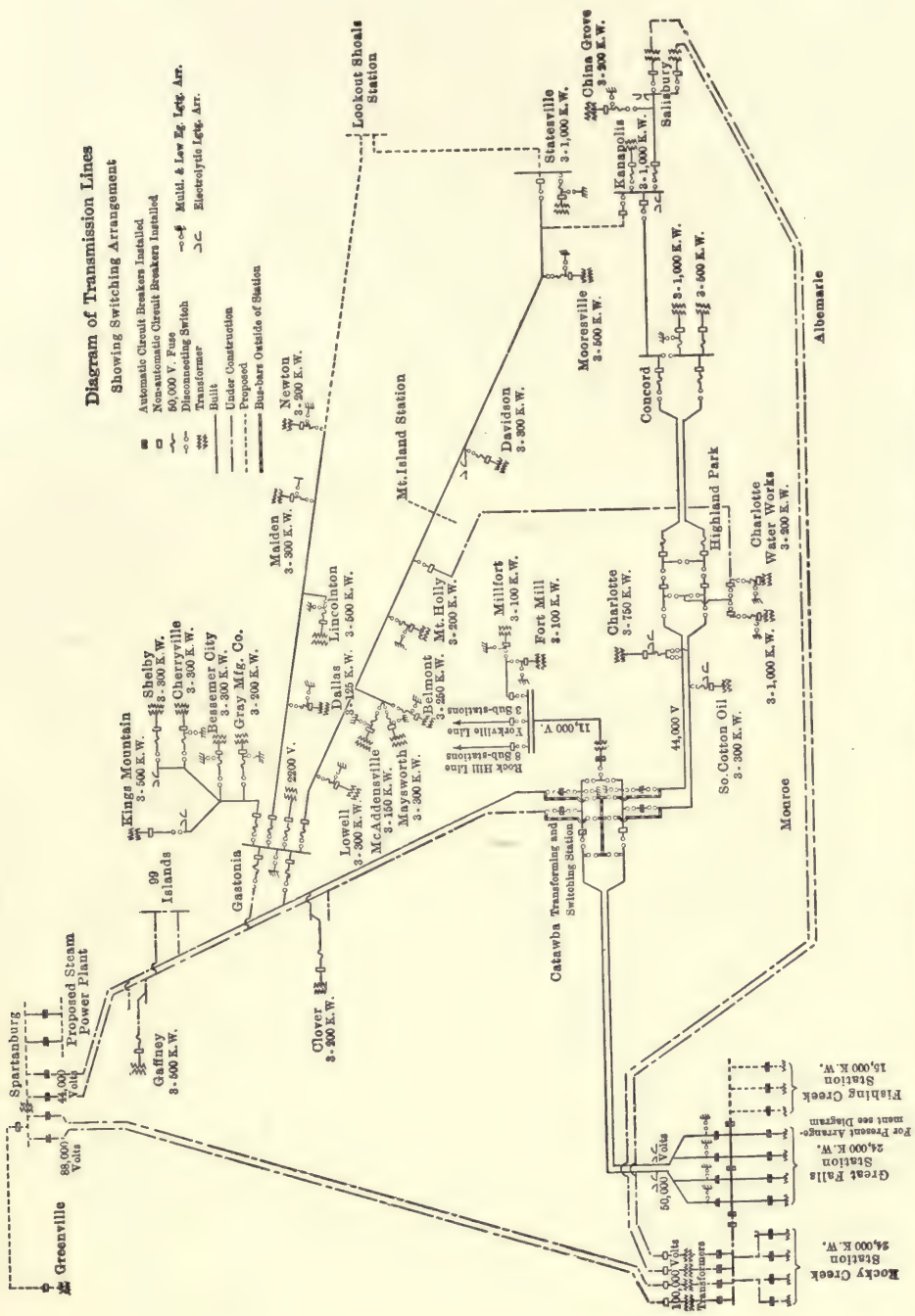


FIG. 11.—Diagram of Transmission and Feeder Circuits, Southern Power Company.

station, a transformer house is being erected to contain 32,000-K.W., 11,000/44,000-volt transformers, with suitable switch gear for running the two stations in multiple.

Both primaries and secondaries of the transformers throughout the whole system are delta connected. By this arrangement, the line voltage may be raised, should a higher one be deemed advisable in the future.

Towers. For the 44,000-volt main circuit, galvanized two-circuit steel towers are used. They are of the Aermotor twin type as illustrated in the chapter on steel towers.

Each half is joined to the other at a point midway between base and top. The corner angles of each half are 3 by 3 by three-sixteenths inch, while the two lower inside corner members are 3 by 3 by one-eighth inch angle iron. The two halves are joined together by a batten plate. The width of the base in the direction of the line is 13 feet 2 inches, while in the opposite direction, 14 feet 6 inches. The cross-arm brackets are of $2\frac{1}{2}$ by $2\frac{1}{2}$ by one-eighth inch angle, braced by 2-inch pipe. Upon 2-inch pipe insulator pins are mounted Thomas insulators, 13 inches high and 12 inches diameter.

A six-strand cable with a hemp core, equivalent to No. 000, is used for the main three-phase circuit, located at the corners of the triangle-shaped towers, 6 feet on the leg.

The spacing of the towers is approximately 420 feet, there being 12 towers to the mile. The standard tower is 35 feet high from the ground to the lowest conductor; there are a few 43 and 50-foot towers. They weigh 2400, 3000, and 3500 pounds respectively. The four legs of the twin towers are bolted to angles embedded in a concrete footing.

The standard 35-foot towers stood the following tests: first, a horizontal pull of 1000 pounds applied at the top of each insulator pin; loads were applied both in the direction of the line and at right angles thereto. Second, a horizontal pull of 8000 pounds applied across the two apices of the tower, both in the direction and at right angles to same. Third, when tested to destruction, the tower collapsed at a corrected pull of 14,000 pounds applied across apices of the tower in the direction of the line.

Financial Aspects. In discussing the market at the time the Southern Power Company was organized, the field of distribution, of course, was well considered. The power was to be used largely for the operation of cotton mills which possessed their own plants. Investigation showed that it amounted to approximately 200,000 HP., one-fourth of which is water power.

The fundamental requirements for all power developments are, a sufficient source of power, and market for same, and necessary capital. To make the development of the Southern Power Company's system a paying one, of course thorough investigations were made, and the following is an abstract by Mr. Fraser on this subject.[1]

Before investing in the sites, a careful investigation showed the average cost of power to be in the neighborhood of $34 per brake-horsepower-year of 3366 hours; that, although a few of the larger mills had this cost down to $30, the majority of the

[1] Some Engineering Features of the Southern Power Company's System, by J. W. Fraser. *Am. Inst. E. E.*, Atlantic City, N. J., June 30, 1908.

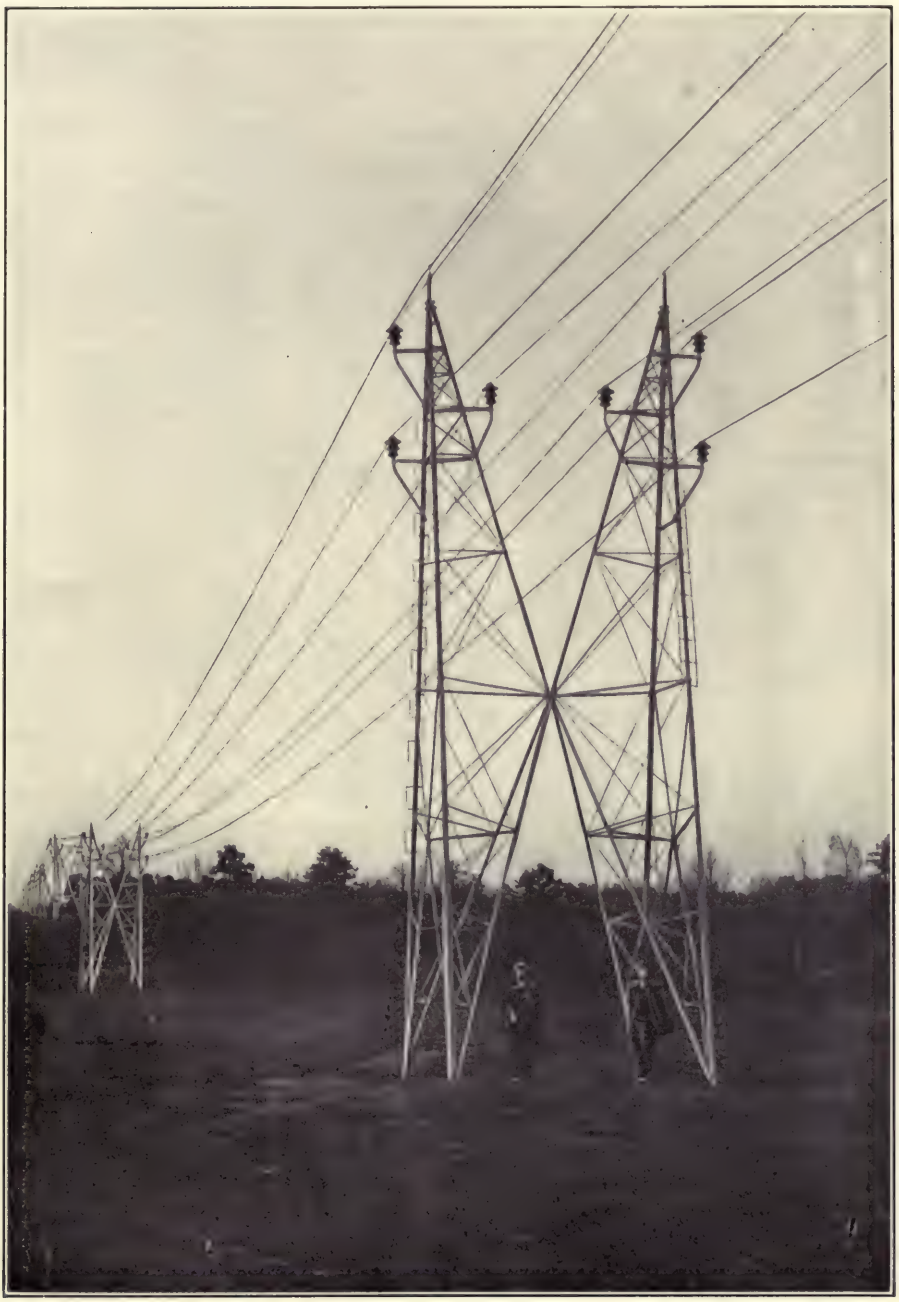


FIG. 12.—Main Transmission Line, between Great Falls and Catawba.

smaller mills could not produce power for much less than $40. With coal at $3.50, power could not be distributed for less than $28, even from large central steam stations. Experience acquired from the Catawba station and some smaller stations, to the records of which access was had, showed a fair margin of safety after transmission and other losses were taken into account.

True it is, that in recommending investment in these sites, it had to be considered that although the electric drive had demonstrated in some instances its reliability, convenience and economy, yet the unsatisfactory history in other instances, the general impression that power was produced for much less than it actually cost, and the fact that mill owners were averse to further investment, would make the sale of power a difficult matter. Still, the main question which interested the investor was the cost of steam power, for prejudice could be overcome and the real cost of power could be demonstrated. In a further discussion of the market, it is found convenient to treat it under separate heads embodying the various engineering features.

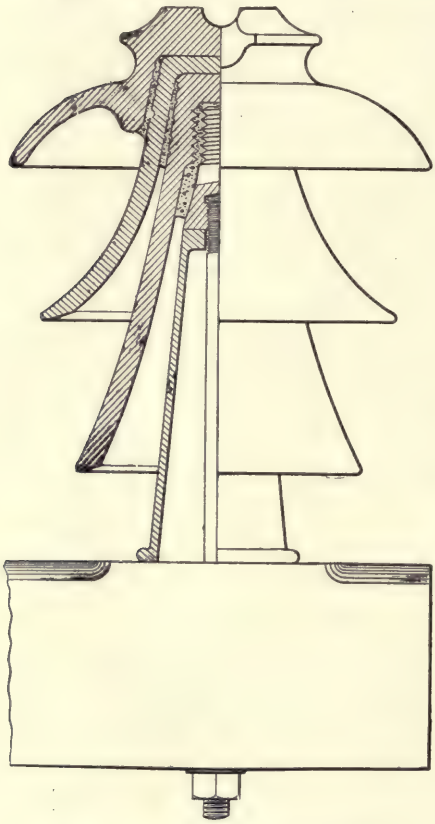


FIG. 13.—50,000-volt Insulator, Southern Power Company.

Frequency. In determining what frequency would best suit the market conditions, the following had to be taken into consideration.

a. That the sixty-cycle generators at Catawba station and some 8000 to 10,000 HP. in induction motors receiving power from that station would have to be rewound or exchanged if other than sixty cycles were used, on account of the fact that separate lines would be too expensive and would complicate matters. Motor generators would make the cost prohibitive, because of the large number of distributing points.

b. That sixty-cycle motors to a total of approximately 8000 HP. were driving mills in the vicinity of proposed lines, which load might be obtained, provided the frequency was the same.

c. That there were also quite a few small city plants operating at sixty cycles. At present this might not amount to much, but the growth of these cities had to be considered, particularly in reference to arc lighting. In three years, 2500 arc lights have been put in service, and if motor generators had had to be installed, the cost to small mill towns would have been excessive.

d. That a high frequency would give a better power factor, due to the leading charging current.

e. That twenty-five-cycle generators, transformers and motors would cost at least

10 per cent, 25 per cent and 10 per cent respectively, more than sixty-cycle generators, transformers and motors.

f. That there was very little prospect in the near future of a rotary converter or railway load, and there were plenty of cotton mills in the district covered to use all the power which could be generated from the rivers.

Against the above is the extra line drop, but when all the developments are completed very little power will be transmitted more than forty miles, except over trunk lines, where the drop may be taken care of by raising the generator electromotive force. For instance, the voltage at Catawba and at Spartenburg, two centers of distribution, can always be maintained at 44,000 volts.

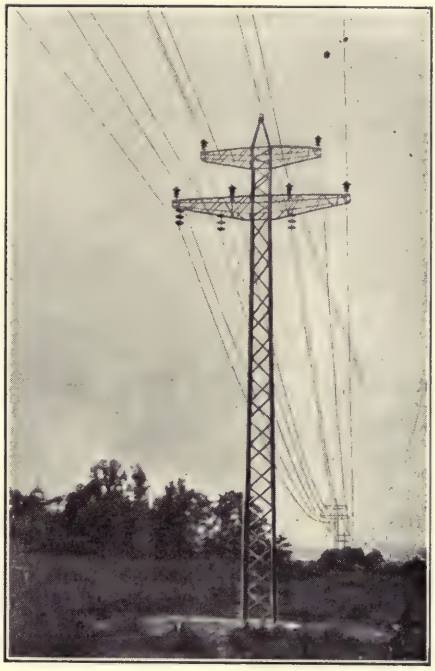


FIG. 14.—Tower used for Lines in Cities, Southern Power Company.

These conditions seemed to favor sixty cycles, but as exact figures were necessary in this case, the following rough calculation was made. The saving in cost of generators and transformers amounted to $75,000, and if the saving in copper due to increased power factor is added, the total will be in the neighborhood of $100,000.

There is an additional loss of about ten per cent of the loss which there would have been at 25 cycles, and the integrated loss over the present lines when fully loaded will be in the neighborhood of 27 per cent. In power, this amounts to 10 per cent of 27 per cent of 26,000 K.W. = 700 K.W., which at $5 per K.W. is $3500. Capitalized at 6 per cent this amounts to $60,000 — a balance of $40,000 in favor of sixty cycles. It is possible that a very careful analysis might show this loss to be a little greater, but the error cannot be over 25 per cent, as the integrated loss referred to has been taken over a period of six months and covers losses from generators to meters on load. The only other error which could be made would be in estimating the line drop, when the present lines were fully loaded, but as the drop on the present load has been measured, the error could not be very large.

Considerations a, b and c have been left out of the above numerical calculation, but might easily amount to several times the figure mentioned.

Voltage. Some of the reasons for keeping the E.M.F. as low as 44,000 volts were:

a. That 44,000-volt transformers would cost from 18 per cent to 33 per cent, depending on the size, less than for 66,000-volt transformers.

b. That transformers and switches were more reliable at 44,000 volts.

c. That each insulator would cost about 80 per cent less.

d. That line operation would be more successful.

e. That smaller transformer stations could be built.

It was estimated that the extra copper to give the same drop over the entire system at 44,000 volts as compared with 66,000 volts would not exceed the extra cost of transformers, insulators, substations, switches and other apparatus. The estimate proved correct. With the present 30,000-HP. load there are on the system 72,000 K.W. in step-up and step-down transformers, and the additional cost, if 66,000-volt transformers had been used, would have been $64,000; additional cost of 30,000 insulators at eighty cents, $24,000; additional cost of thirty 66,000-volt substations, i.e., 20 per cent on $125,000, $25,000; additional cost of step-up transformer stations, i.e., 10 per cent on $200,000, $20,000; a total of $133,000. Against this is the saving in copper in the transmission line had the higher electromotive force been used, roughly, 50 per cent, $130,000.

This shows a saving of only $3000, but the present lines will carry a great deal more power than they are now carrying, which will increase this amount materially.

One only, of those proposed, stands out as an exception, the trunk line running from Great Falls to Spartenburg and thence to Greenville, about 100 miles in length. This line, now under construction, will be so built that when overloaded at 44,000 volts delivered E.M.F. can be changed to 88,000 volts (i.e., 100,000 volts at generating station). This will be accomplished at a very small additional expense, by mounting pins and insulators, similar to those now used on our wood pole lines, on the towers, for after conversion to a higher E.M.F., these pins and insulators can be used on 44,000-volt lines, or this line may be permanently used for local distribution. The intention is, that this 88,000-volt trunk line will not be tapped at any point except Spartenburg. This could be done more easily by using 100,000-volt suspension type insulators, but it is felt that by the time it is necessary to change to the higher E.M.F., there may be enough improvement made in these insulators to warrant the extra expense which would be then incurred.

Transmission Lines. Further examination of the transmission line map shows that two-thirds of the obtainable power is in the neighborhood of the Great Falls development, which position was selected as a main switching station; the idea being, to mass the output of Great Falls, Fishing Creek, Rocky Creek and Rich Hill at this point on outdoor bus bars, and control the line switches from the operating room in this station.

The generators and transformers were designed to operate continuously at 85 per cent power factor to take care of an induction motor load, and at 115 per cent normal E.M.F. to take care of line drop as the load increased. The main trunk line, from Great Falls to Catawba station, will take care of 20,000 K.W. at 85 per cent power factor, with a line drop of 13.5 per cent and a loss of 7.25 per cent. This represents the economical section of copper at twenty cents per pound with power costing $5 per K.W. year.

It should be pointed out, before leaving the subject of transmission lines, that the impossibility of making contracts with mill owners on account of their skepticism with regard to electric drive, before the greater part of the present lines were actually built, made the estimate on the amount of power to be sold in any one territory so difficult, that the location and size of transmission lines could not be determined even

approximately. In other words, where and in what amounts power was to be sold was a very uncertain matter.

This brought up the question of wood pole lines versus steel towers. A little consideration showed, that if the cost of towers per additional foot in height erected, was seven dollars, and copper at twenty cents per pound, a No. o Brown & Sharp gauge would be the smallest wire which could be strung economically on account of the increased sag in wires below this size for 500-foot spans; that a single circuit tower line would cost approximately twice as much as a pole line and would last probably twice as long; that a double circuit tower line would cost very little more than a double pole line; and that it would be more economical for cotton mills to shut down for a small percentage of time, than to pay the additional price for power which would be necessary to cover the extra expenditure for steel tower lines. It therefore seemed good practice to build main trunk lines of steel towers, and all single lines below No. o gauge, of wooden poles.

Secondary Power. From government records and from six years of gaugings before the completion of the Catawba plant, together with two years' operating experience, the flow of the Catawba River had been pretty well determined.

The question which presented itself most forcibly was, whether to develop the average minimum twelve months' flow or to develop for ten months, eight months or less, and to supplement with steam power; a problem which has to be determined by the first cost of development and by local market conditions.

In following calculations where the cost of primary and secondary power is taken at a fixed rate, the intention is not to convey the idea that these are actual figures, but relative figures which will serve the purpose of this paper.

There are many different solutions to the problem of ascertaining the amount of secondary power which may be economically developed. At one of our developments, it was found that the average minimum primary power was in the neighborhood of 16,000 K.W., and that the increase per month of secondary power was in the neighborhood of twelve and one-half per cent, i.e., 2000 K.W. per month.

In other words, if secondary power was to be developed for eight months' sale, the total development of primary and secondary power would be 24,000 K.W. If this secondary power can be sold without an auxiliary steam plant, the amount of secondary power which may be developed economically depends only upon whether or not the price received for such power will cover interest and profit on the investment; that is, the investment which is over and above that for developing primary power; but if a steam plant has to be maintained, the amount of secondary power to be developed depends also on the cost of steam power. It is very clear that the cost of secondary power is practically the same whether it is sold for eleven months or one month. With this cost, say at $10 per HP. delivered, steam at $28 per HP. year ($6 interest and depreciation, $22 for coal, operating expenses, etc.), if interest and depreciation on the steam plant is entirely chargeable to the months when steam plant is in operation, then

Cost of steam power per month $= 1.83 + 6/x$
when $x =$ the number of months in operation.

Amount of secondary power to be developed = 16,000 kilowatts $\times$ $12.5x/100 = 2000x$.

Cost of steam-secondary

$$= 2000x\ (1.83 + 6/x)x + 2000x \times 10$$
$$= 2000\ (1.83x^2 + 6x + 10x).$$

If power is selling at \$20, profit

$$= (2000x\ 20 - \{2000\ (1.83x^2 + 16x)\}$$
$$= 2000\ (20x - 1.83x^2 - 16x).$$

For max. $dy/dx = 3.66x = 3.66x - 4$

$$x = 1.1 \text{ month.}$$

On this basis, maximum profit would be made on 2000 K.W. secondary development.

A more practical method under existing conditions seems to be to charge the interest and depreciation of steam plant to the operating expenses of the system, inasmuch as the steam plant is an insurance against a partial shut-down and makes spare units unnecessary, and in the case of steam turbines, when run as synchronous motors, saves copper because it brings up the power factor. The above equation now becomes:

Cost of steam + secondary

$$= 2000x\ (1.83x) + 2000x \times 10)$$
$$= 2000\ (1.83x^2 + 10x).$$

Profit

$$= 2000 \times 20 - (2000\ (1.83x^2 + 10x)$$
$$= 2000\ (20x - 1.83x - 10x)$$
$$= 2000\ (10x - 1.83x^2)$$

(For max.) $dy/dx = 3.66x - 10$

$$x = 2 - 3/4.$$

Maximum profit on this basis would be made on 5500-K.W (35 per cent) secondary development.

Had \$24.50 been taken as the selling price of power, x would equal four months, or the total development should be made for 150 per cent of mean average low water. Although power from hydroelectric plants has been selling in the Carolinas for less than this latter figure, there is no doubt that reliable service demands this price.

THE NECAXA PLANT, MEXICAN LIGHT AND POWER CO.

Mexico, a country where industry is growing rapidly, recognized at an early date the advantage of utilizing high water falls and transmitting the power by high tension lines to the centers of consumers. As early as 1901,[1] a 50-foot fall of the Lerma River at Juanacatalan was utilized by belt-driven, single-phase turbine generators, and the energy transmitted on iron poles over a distance of 17 miles to the city of Guadalajara, the potential being 5000 volts. In the year 1895, a 10,000-volt transmission line was installed, transmitting the energy of the waterfall at Regla to Pachuca, where it was used in the cities and mills, as well as for operating the mines of the Rio del Monte Company. The generating voltage was 700, three-phase. The turbines, of which there are five, are of the impulse type, operating under an effective head of 800 feet.

The Guanajuato Power and Electric Company erected at Zamora, in 1903, a power plant which utilized a head of 320 feet. The water was supplied by a canal 5 miles long and a penstock 3300 feet in length. Two 1125 HP. impulse wheels are connected to a 1250-K.W. three-phase, 60-cycle generator running at 200 R.P.M. By a step-up transformer the voltage was increased to 60,000 and the power transmitted over a line 110 miles long to Guanajuato, supplying the silver mines and mills. The line is 40 to 50 feet above the ground, supported on galvanized steel towers placed 450 feet apart on the average, the longest span being 1500 feet.

Necaxa Plant. The largest and most prominent of Mexican plants now in operation is that of the Mexican Light and Power Company at Necaxa, utilizing the waters of the Tenango and Necaxa rivers.[2] It is designed for capacity of 20,000 HP., operating under a static head of 1452 feet, and transmitting energy at 60,000 volts to the City of Mexico and the gold mines of El Oro. This transmission line is 160 miles in length.

There is in view, besides the above, the utilization of the tailrace and other sources under a head of 700 feet, also developing 20,000 HP. Should there be a demand for more power, the company is in a position to provide for some 30,000 HP. additional, under a head of 2100 feet. If this is ever done, it is proposed to increase the voltage from 60,000 to 80,000, for which the line has been designed.

As the power plant is located in a very inaccessible part of the state of Puebla, to facilitate the construction of the plant, it was necessary to build many roads and trails as well as some 30 miles of railroads. For a vertical distance of 1500 feet, the machinery and other material had to be lowered by cableways down steep cliffs to the power house. The cableways were capable of handling 15 tons. Furthermore, a temporary power plant had to be built with two 500-HP. Pelton wheels connected to 500-volt direct current generators. Engineering camps were located on a mesa 1700 feet above the power house, and for giving shelter to the working 4000 Mexicans, three new towns were built to replace the towns flooded by the reservoirs.

[1] Electric Power Developments in Mexico, by F. O. Blackwell. *Cassier's Magazine*, July, 1905.

[2] "The Necaxa Plant of The Mexican Light and Power Co.," by F. S. Pearson and F. O. Blackwell, Am. Soc. C. E., Vol. LVIII, p. 37, 1907.

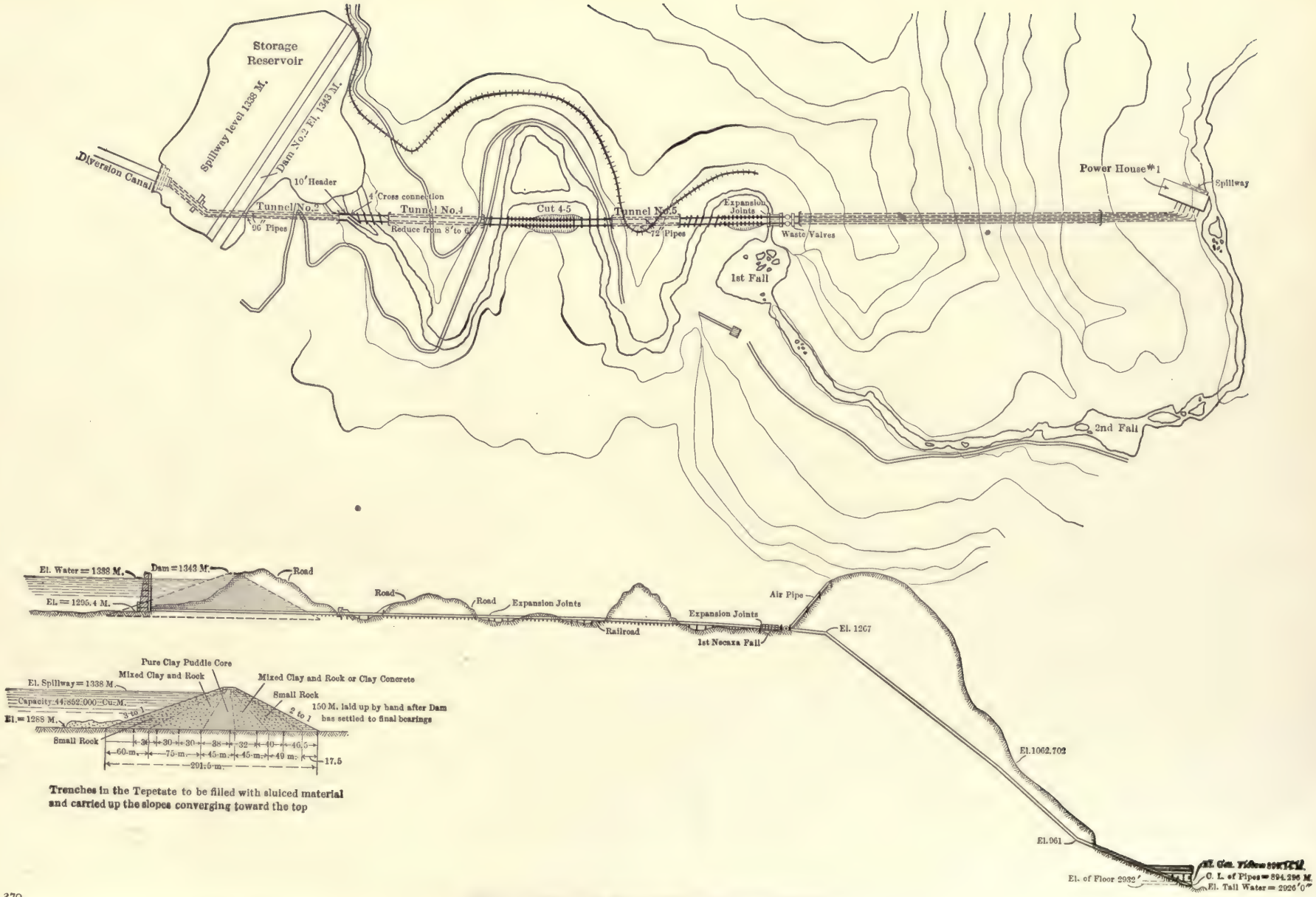


FIG. 1.—Necaxa Power Development, Mexico.

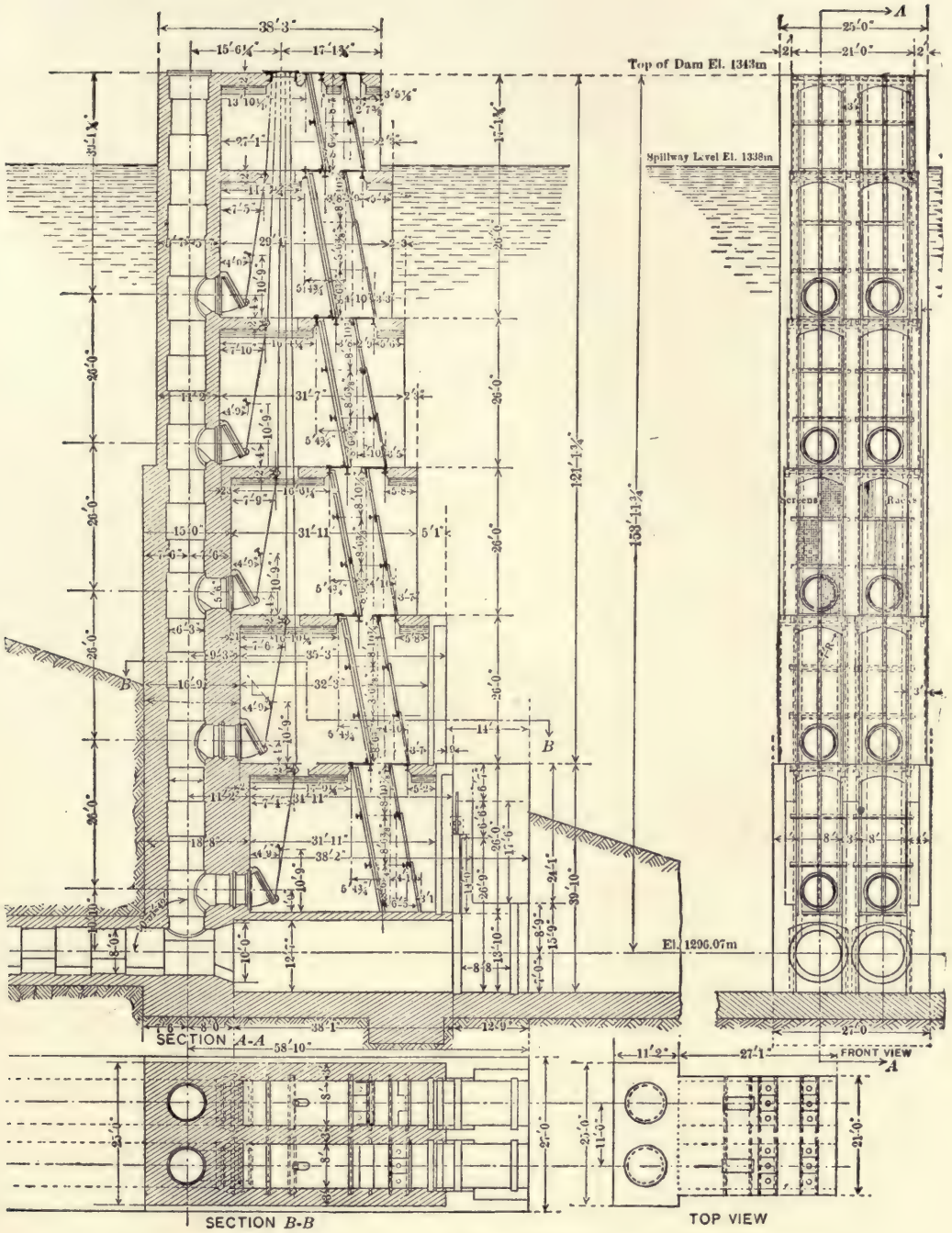


FIG. 2.—General View of Intake for Dam No. 2, Necaxa Plant, Mexico.

Drainage Area. The drainage area of the Tenango and Necaxa rivers is a portion of the plateau on which the City of Mexico is situated, and contains 227 square miles. In the course of 3 miles the water drops through the several falls, ranging from 300 to 800 feet, some 3000 feet. The combined average flow throughout these rivers is 245 cubic feet per second, while the minimum, 35, and maximum, 3000 cubic feet, is reached only at certain periods of the year. The average flow for a period of seven years was 350 cubic feet per second.

The water of the Tenango is diverted into the Necaxa by means of a 40-foot dam and a 3000-foot tunnel, 9 feet high and 12 feet wide. The tunnel has a pitch of 4 feet in 1000, and is sufficient to carry all except extreme flood water. There are several storage basins on the Necaxa; the one furthest down the stream is the Necaxa, having a capacity of one billion five hundred and eighty-five million cubic feet. Above the Tenango tunnel are the Texcopa, of six hundred and forty-two million, and the Laguna Reservoir, of seven hundred million cubic feet capacity.

It is proposed to increase the latter reservoir to a capacity of 2450 cubic feet. This will be accomplished by diverting Los Rayos and its tributaries into the reservoir. This storage capacity will then amount to four billion six hundred million cubic feet, and will be ample to provide the requisite average for many years.

Dams. Owing to the volcanic origin of the country, it was not advisable to construct masonry dams. For this purpose, earth dams were constructed by the hydraulic fill method, utilizing water heads up to 400 feet. The Necaxa dam is 180 feet high, with a thickness of 95 feet at the base and 54 feet at the crown, the latter being 1276 feet long. The slope on the upstream side is 3 to 1, and on the downstream side, 2 to 1. The faces are covered with broken stone 60 feet thick at the bottom and 18 feet at the crown. Two million cubic yards of material were used in its construction. For method of construction of this dam, see Chapter III, Dams.

The Texcopa dam is 174 feet high and 1190 feet long at the top. The thickness at the base, 905 feet. It was built by the same scheme as the former. The present Laguna dam is 40 feet high and has a length of 400 feet. On the north side of the Necaxa dam is provided a spillway; on the southern side of the dam are located the penstock connections.

Penstocks. The penstocks, of which there are two, are supplied through two vertical risers, divided into five stages (see Fig. 2). Each stage is provided with a rack, screen and flood gate. Because of the variable quantity of water stored in the dam, this system of stages gives a simple method of operating the flood gates under low head of not more than 26 feet. The vertical risers are located on the upstream side of the dam in a tower-like structure made of concrete.

All racks and screens are located in pockets in this structure, and are easily cleaned and removed. The penstocks have a diameter of 8 feet and are made of three-eighths-inch riveted steel. They go through the Necaxa tunnel, where they are provided with waste valves. From here the pipe is reduced to 6 feet and continues downstream for 2200 feet through tunnels and over valleys. In this run there were about 800 feet of tunnels cut.

Near the first Necaxa Fall, each penstock joins a reservoir 22 feet long and 7 feet

in diameter. From each of these two reservoirs lead three 30-inch penstocks through an inclined tunnel down to the power house. Near the junction of the 30-inch pipes and reservoirs is connected to each of the 30-inch pipes a 30-inch air pipe extending 310 feet up a mountain slope to an elevation above the top of the dam. All penstocks are provided with gates at the reservoir and a central gate separated into two halves, so that either half can be shut down without interfering with the other. The 30-inch penstocks are provided with pack slip joints, while the 6-foot pipes are supplied with expansion joints of the diaphragm type.



FIG. 3.—Dam and Penstock, Necaxa Plant, Mexico.

When the plant is running at normal full load, the velocity in the 6-foot penstocks is 7.5 feet, and in the 30-inch penstock is 15 feet per second. When running under extreme overload, the velocity of the water in the 30-inch pipes is 18 feet.

While the two 6-foot penstocks are of riveted steel, the six 30-inch penstocks are of seamless weld tubes. They were shipped from Germany in sections of 29.5-foot lengths, and are provided with flared ends and loose, movable flanges of special design. The inside diameter of the 30-inch penstocks at the power-house end is

29 inches. The thickness of these tubes varies from 0.5 inch to 0.95 inch. Each of the six 30-inch penstocks is 2460 feet long; the length of upper sections is 1900 feet. They run through two parallel tunnels, each being 13 feet wide and 10 feet high and run on an incline of 41 degrees.

All pipes and penstocks are supported on concrete piers. The static head, with filled reservoir, is 1452 feet at the turbine; due to friction, this head is reduced to between 1200 and 1300 feet.



FIG. 4.—Power House of the Necaxa Electric Light and Power Company. In Background 2nd Necaxa Falls, 740 feet High.

Power-Plant Building. The power house is located in the bottom of a canyon 740 feet deep. The building is 235 feet long, 88 feet wide, and 37.5 feet from floor to roof truss.

It is divided in the middle longitudinally by a partition wall, separating the generating room from the switching and transformer room. In the basement of the generating room are the turbines, while penstocks enter beneath the transformer room.

The whole structure, sub and superstructure, is of concrete. The generating room has steel columns carrying the runways for a 40-ton electric-operated crane and the roof truss. The latter is carried on the switching room side, on the walls.

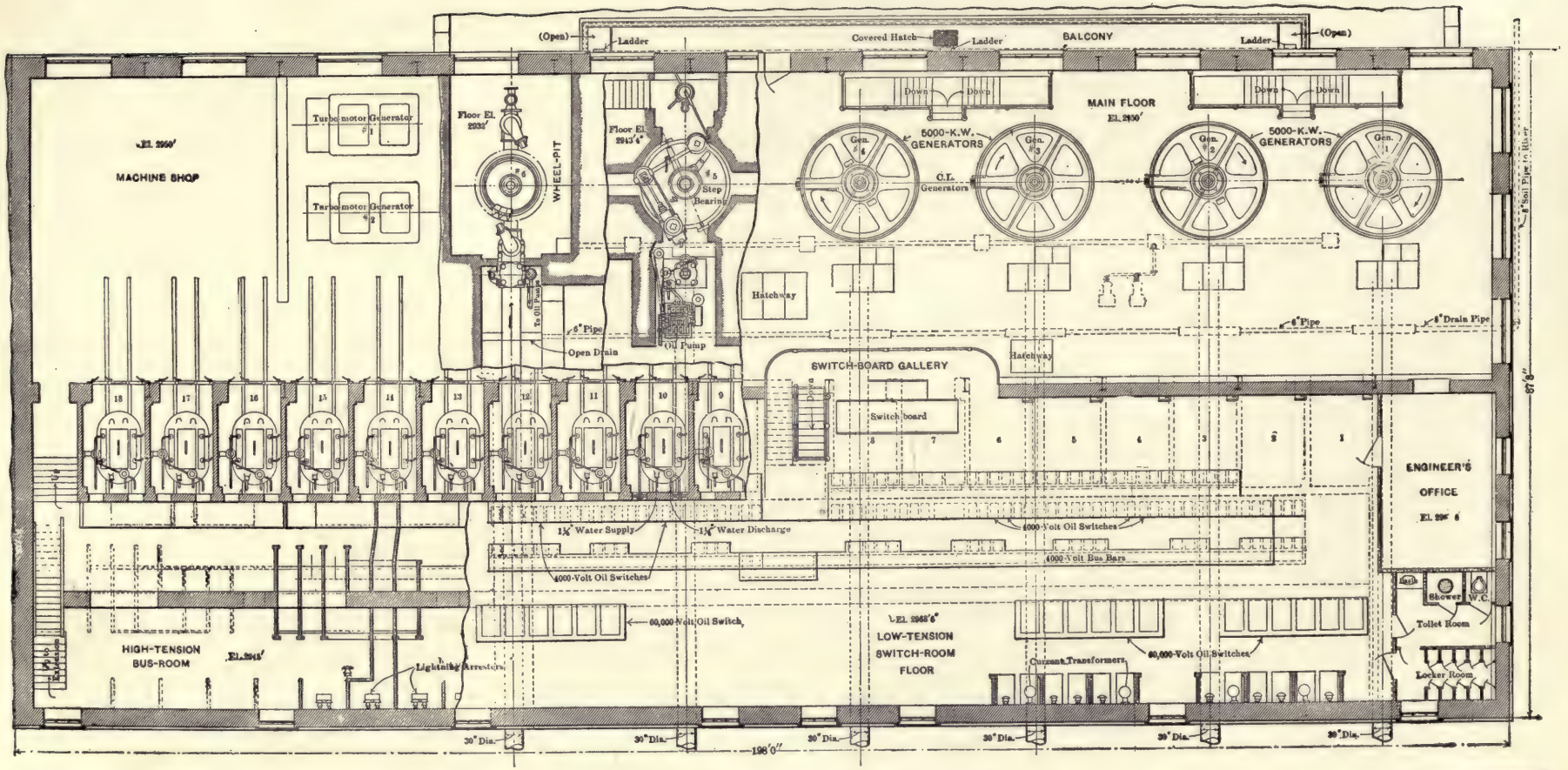


FIG. 5.—General Plan of Necaxa Power Plant.

A.E.&M.
UNIV. OF

Turbines and Regulators. There are installed six impulse wheels mounted on vertical shafts, each having a rated capacity of 7000 HP. and a maximum of 9000 HP. The wheels, 100 inches in diameter, are supplied through a 28-inch gate valve, and make 300 R.P.M. They are solid cast steel disks, to which are bolted 24 steel buckets.

For each wheel there are two 4½-inch square regulating nozzles, situated diametrically opposite; both are connected by a single automatically operated valve, which opens and closes the nozzles simultaneously. This arrangement prevents the

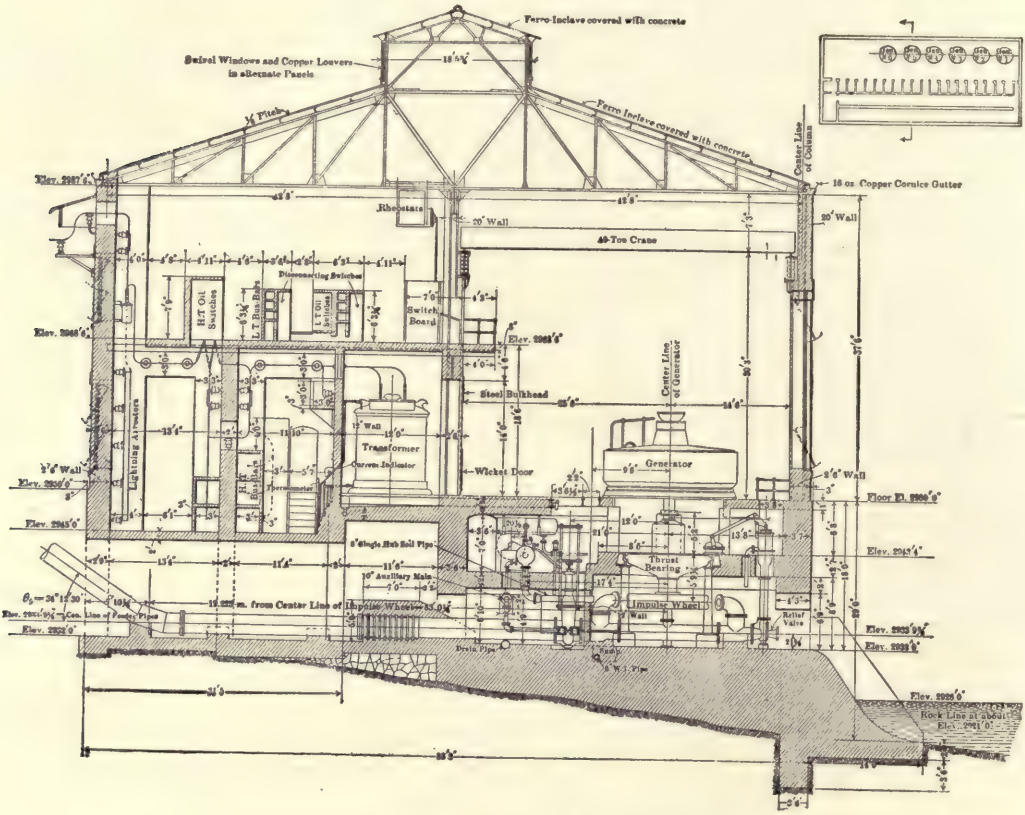


FIG. 6.—Cross Section of Necaxa Power Plant, Mexico.

possibility of water hammer. At the end of the present penstocks in the power house are located relief valves. The maximum quantity of water for each wheel is adjusted by the governor, by means of a by-pass, which is adjusted to close slowly so that little water will be wasted. All turbines and governors were supplied by Escher, Wyss, Zürich, Switzerland.

Generators. Each turbine is connected to a 5000-K.W., three-phase revolving field, 50-cycle, 4000-volt alternator. Two of these alternators are provided with a 60-K.W. exciter, mounted upon an extension of the shaft. Besides this, there are two 250-K.W., 225-volt induction motor-driven exciters. For ordinary service, these motor-driven sets are used; only in emergency cases are the exciters on the generating

shaft employed. The generators and motor-driven exciters were supplied by the Siemens-Schuckert Werke, Berlin.

Wiring System. There is a high and low tension bus, between which are located the transformers. Sufficient oil and disconnecting switches are supplied so that there will be a continuity of service. The outgoing lines are well protected with lightning arresters.

Switching Room. The switching room has two floors, the lower one containing the transformers, high tension busses and lightning arresters, which are separated by

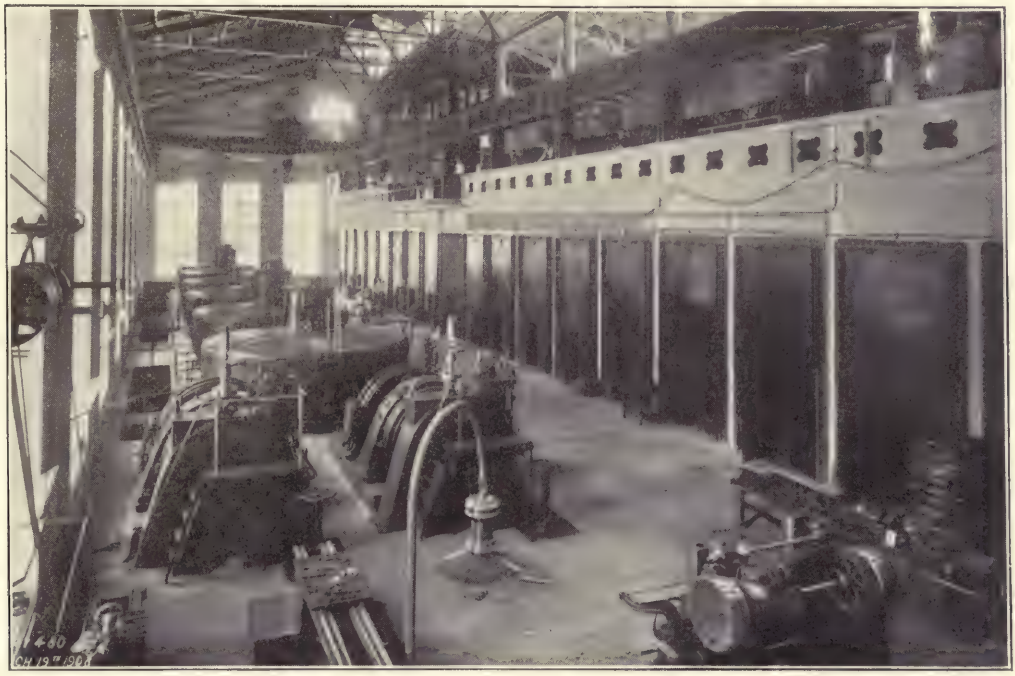


FIG. 7.—Interior of Necaxa Plant, Mexico.

partition walls running lengthwise. The upper floor contains the switchboard, in front of which is a gallery overlooking the generating room. Here are also located the low-tension and high-tension oil switches, between which are the low-tension bus bars. The current transformers are also located on this floor (see general plan of power house). At one end of this floor are the offices, lockers, etc.

Transformers. The transformers are of the single-phase, 2000-K.W., General Electric Company, oil-cooled water circulating type, designed to step the generator voltage from 4000 to 40,000/50,000/60,000. To facilitate inspection and repair, the transformers may be wheeled on tracks into the generating room, and there handled by an overhead crane. Each transformer compartment is provided with a steel bulkhead.

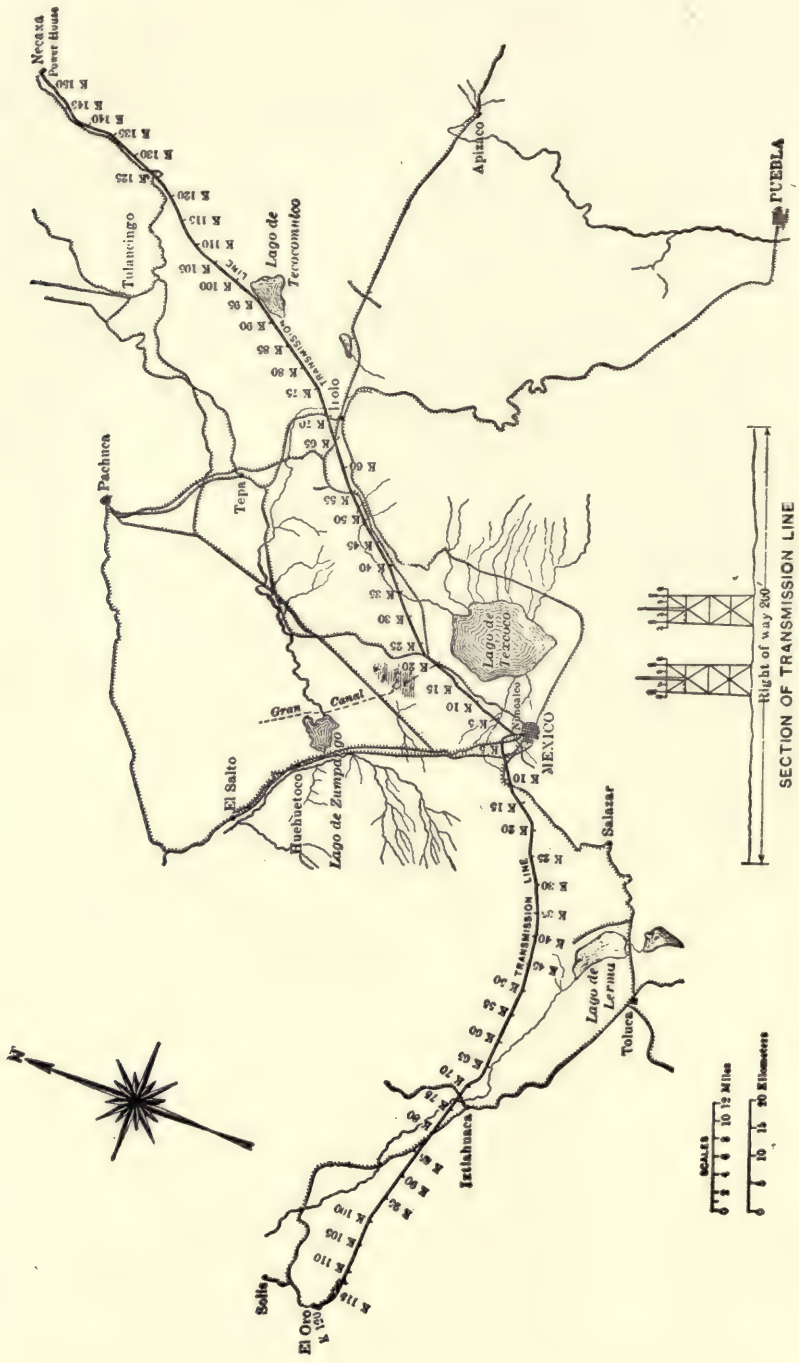


FIG. 8.—Map showing Transmission Line between Necaxa, Mexico City and El Oro.

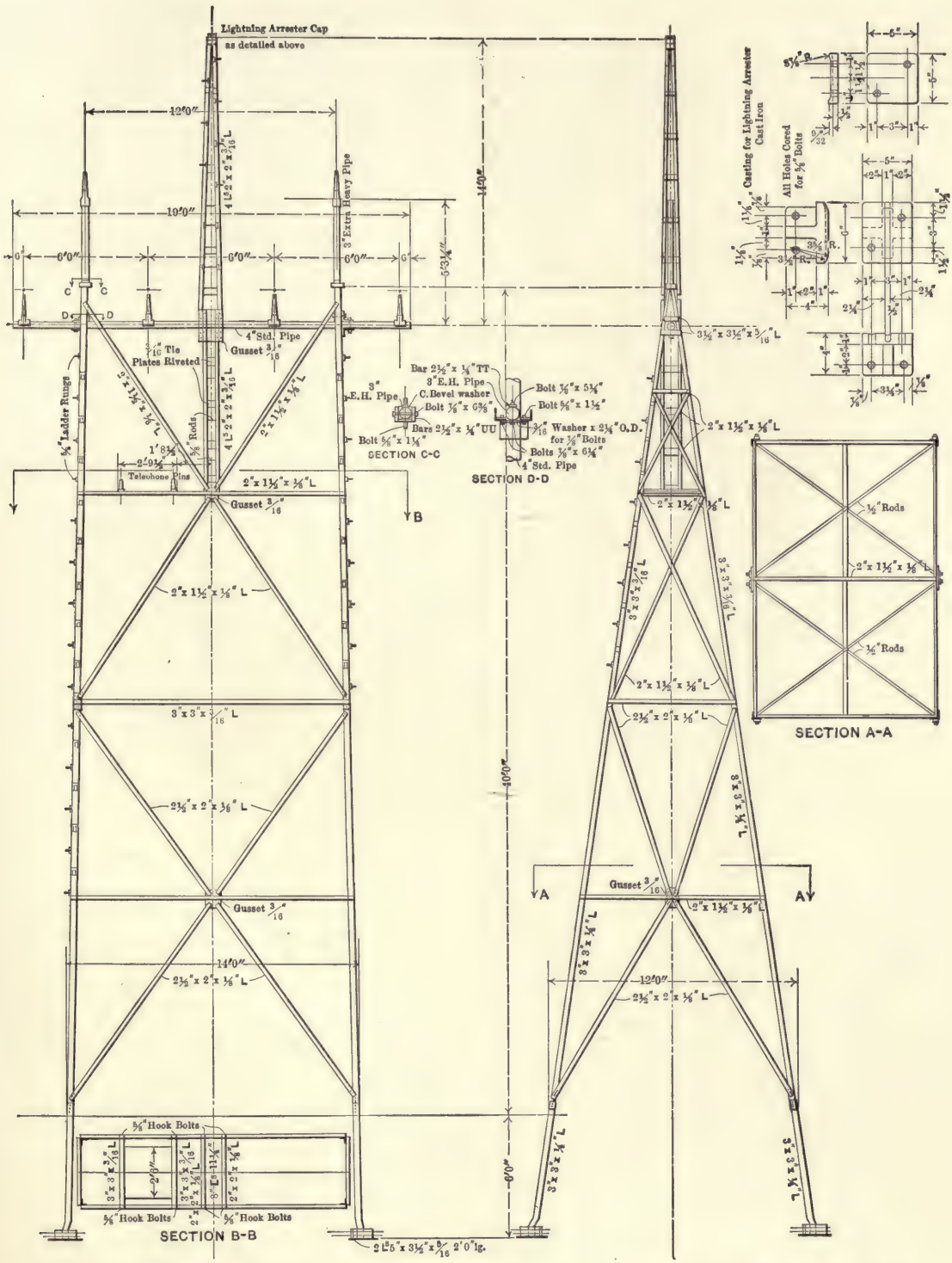


FIG. 9.—40-foot Transmission Tower, Necaxa, Mexico. Similar Type of Tower is used in the 80,000-volt Transmission Line between Rio das Lages and Rio de Janairo of the Rio de Janairo Tramway, Light and Power Company, South America.

Oil Switches. The oil switches, both high and low tension, are of the General Electric Company, remote-control type and operated from a control bench, in front of the switchboard, provided with a dummy bus bar system.

Switchboard. The switchboard is built of ornamental ironwork; the panels are of enameled slate and equipped with the necessary indicating and recording instruments as employed in most up-to-date power-house practice.

Transmission System. The present transmission system consists of two tower lines of two circuits each, running from the power plant to the City of Mexico, some 94 miles, and from here to El Oro mines, a distance of 75 miles. It has been designed

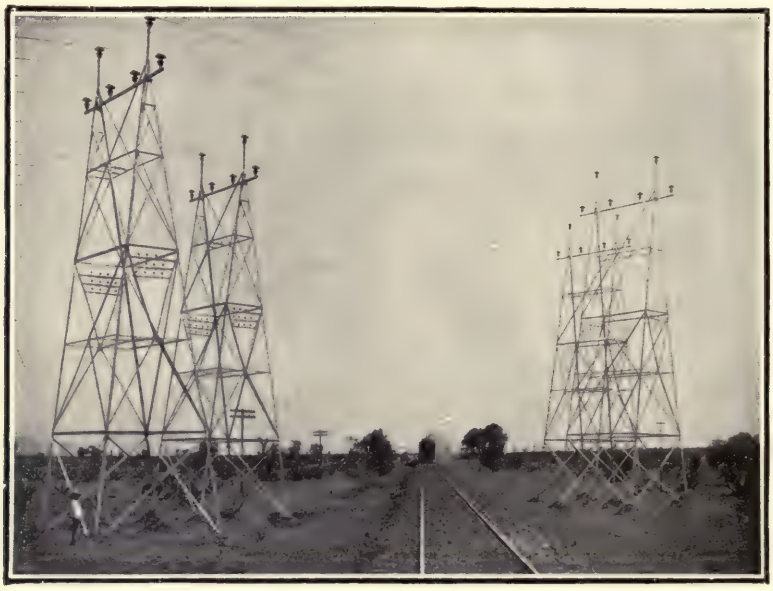


FIG. 10.—Necaxa Transmission Lines towards City of Mexico.

with an eight per cent line loss between the power house and Mexico, and a 5 per cent loss between Mexico and El Oro, thus giving a total line loss of 13 per cent at 100 per cent power factor and 60,000-volt transmission.

Towers. The towers are of the four-legged A-frame type, 14 feet square at the bottom and 12 feet wide at the top. They stick 6 feet into the ground, and are built of angle iron, heavily galvanized, and were shipped knocked down. The circuits are supported on porcelain insulators 40 and 46 feet above the ground. The towers are designed to stand a horizontal side stress of 1650 pounds per insulator pin, or 10,000 pounds per tower, and are calculated to withstand a wind velocity of 100 M.P.H. The average span is 500 feet, but spans as high as 1500 feet were installed, using special structures.

Insulators. The insulators are made of three parts, cemented together on the field. They were tested when wet, at the manufacturer's, The R. Thomas and Sons Company, East Liverpool, Ohio, for a potential of 60,000 volts. After being assembled in the

field, they were tested at 120,000 volts. The insulators are carried on steel pins set in drop-forged sockets.

Conductors. The conductors are six-strand copper cables, one-half inch in diameter, with hemp centers, and have a strength of 60,000 pounds and an elastic limit of 40,000 per square inch. Joints are made with 18-inch copper sleeve every 3000 feet.

Substation. There are two step-down transformer stations, one at Mexico City and the other at El Oro. The substation at the City of Mexico is 210 feet long and 65 feet wide. It is arranged to accommodate fifteen 1800-K.W., single-phase, oil-cooled transformers. They are placed in fireproof compartments and can be removed on tracks and handled by a crane. The step-down transformers are designed to give



FIG. 11.—Substation at El Oro, Necaxa Light and Power Company, Mexico.

1500/3000/6000 volts on the low-tension side. The general arrangement of the substation is similar to the switching and transformer room at the main power house. This station is run in connection with an old Siemens-Halske steam plant, to which four Curtis turbo-generator units, of 500 K.W. each, have been added.

The substation at El Oro is 115 feet long and 59 feet wide. It contains nine 1800-K.W. transformers. The arrangement of the transformers is similar to that in the City of Mexico. The distribution from the substation to the mines at El Oro is 3000 and 6000 volts.

Both substations are well provided with up-to-date switch gear and lightning arresters. At the power house as well as at the substations, the circuit breakers are so arranged as to automatically cut out any section which may become damaged by lightning.

HYDROELECTRIC PLANT, KYKKELSRUD-HAFSLUND, NORWAY.[1]

Norway is one of the richest countries in Europe in water resources. In the last ten years many plants have been erected to utilize these waters. Most of the power is used for industrial purposes, particularly for the iron industry and also agricultural purposes. To utilize the water of the river Glommen, the largest river in Norway, the Aktieselskabet Glommens Traesliberi in Christiana was formed. The well-known Schuckert Company of Nuremburg designed and constructed a plant at Hafslund, and later, one at Kykkelsrud, which is 38 miles southeast of Christiana. Both plants utilize water from the same river and are about 25 miles apart. The first equipment of the Hafslund plant was put into operation in 1899, while the equipment at Kykkelsrud was put into operation in 1903. In 1907 a 50,000-volt transmission system was installed to assist the plant at Hafslund with 8000 K.W.

At the same time, additional equipments were added to both plants, and the two to-day run in parallel.

The river Glommen flows in a southerly direction and empties into Christiana Fjord. Like most Norwegian rivers, it has many tributaries of streams and lakes. It has a drainage area of 16,000 square miles. The highest tributary is 8400 feet above sea level, while the largest lake tributary, Mjösen, has an area of 148 square miles. The area of the lake tributaries is 3 per cent of the entire drainage area of the Glommen. From the data given it is seen that this one river furnishes an abundant water supply for power purposes, when advantage is taken of the many lakes as natural storage basins. At present, the largest plant is utilizing the waterfall at Kykkelsrud under an effective head of some 60 feet, and when the ultimate equipment is reached, 35,000 HP. will be developed.

Headrace. On the left side of the Kykkelsrud Falls, the river Glommen is tapped by an open canal about 40 feet deep, 3300 feet long, which leads the water to a forebay in the rear of the power plant, which is located in a cove some 3500 feet below the falls. As the river is used for floating logs down from the mountains, the inlet to the canal is protected by a floating deflector. The deflector is made up of wooden lattice work and extends some three meters into the water. A wooden deflecting structure was chosen because of the unknown effect the logs might have at certain seasons of the year.

At the entrance of the canal are two sluice gates, separated by a pier. Each sluice gate is divided into five sections to facilitate the regulation of the water. They may be operated by hand individually or by electric motors collectively, for which two 18-HP. motors are installed. When the gates are wide open, the opening has an area of 1500 square feet, giving the water a velocity of 4.1 feet per second. If necessary, this opening can be increased by removing some stop logs.

As stated, the forebay is located in the rear of the power house and is 420 feet long. It is provided at the end with three sluice gates to let out sand, gravel, and anchor ice. One of the gates is used to let out floating material. The spillway is

[1] Die Ausnutzung der Wasserkräfte des Glommens bei Kykkelsrud (Norwegen), by I. H. Kinbach, München. Zeitschrift des Vereines deutscher Ingenieure.

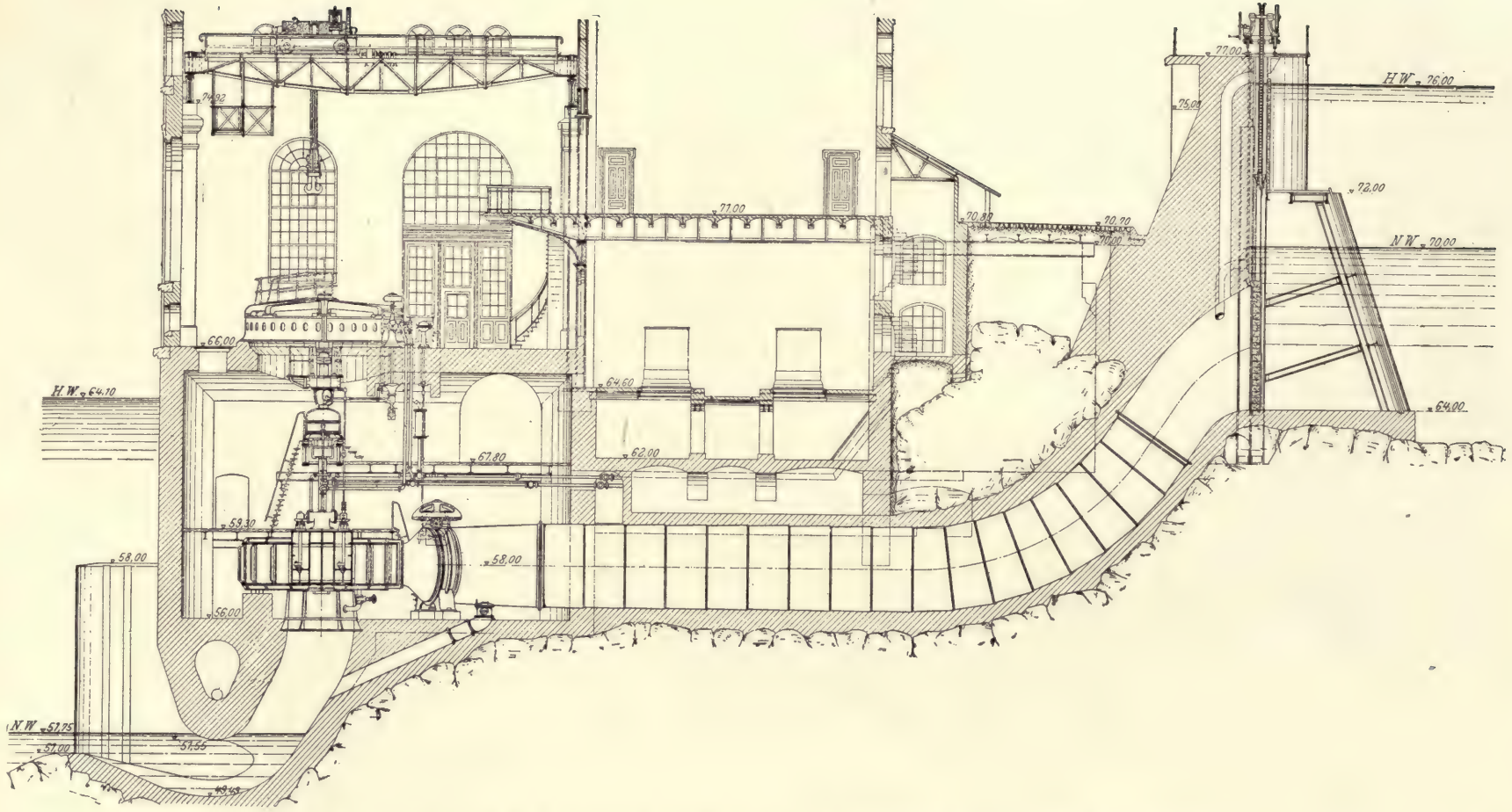


FIG. 1.—Cross Section of Kykkelsrud Plant, Norway. Plan showing Main Turbine Arrangement.

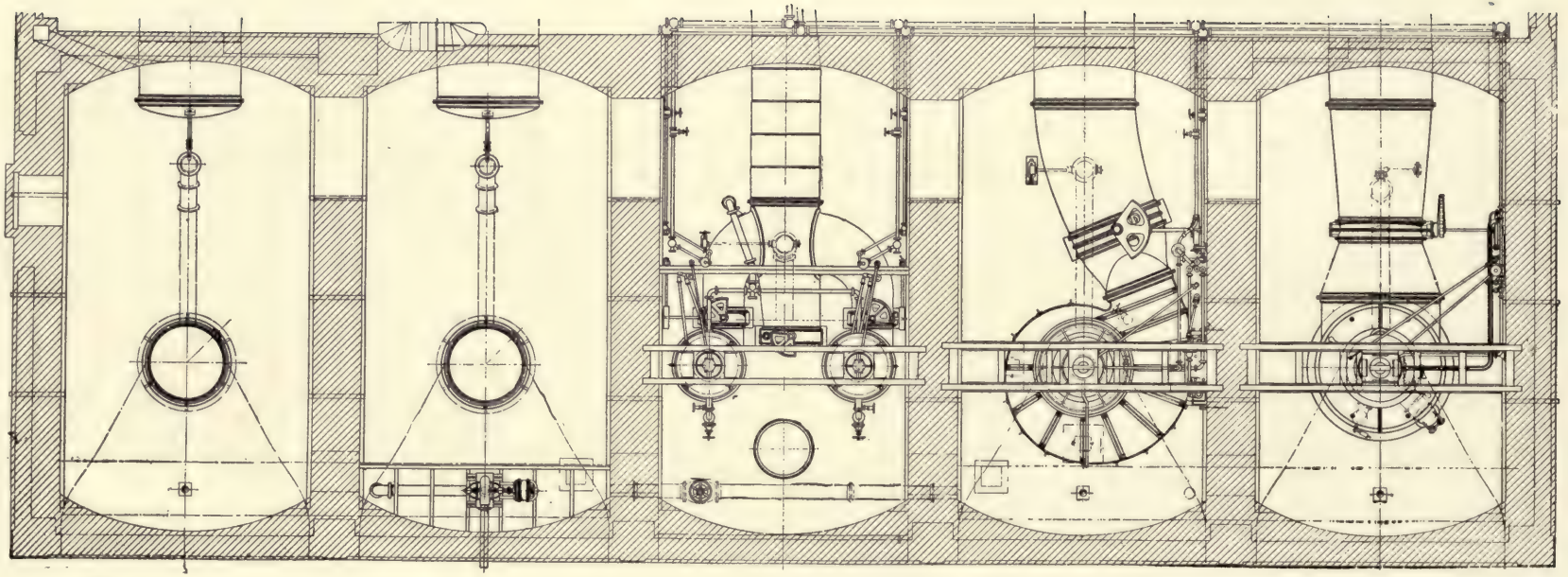


FIG. 2.—Plan of Turbine Chambers, Kykkelsrud Power Plant, Norway.

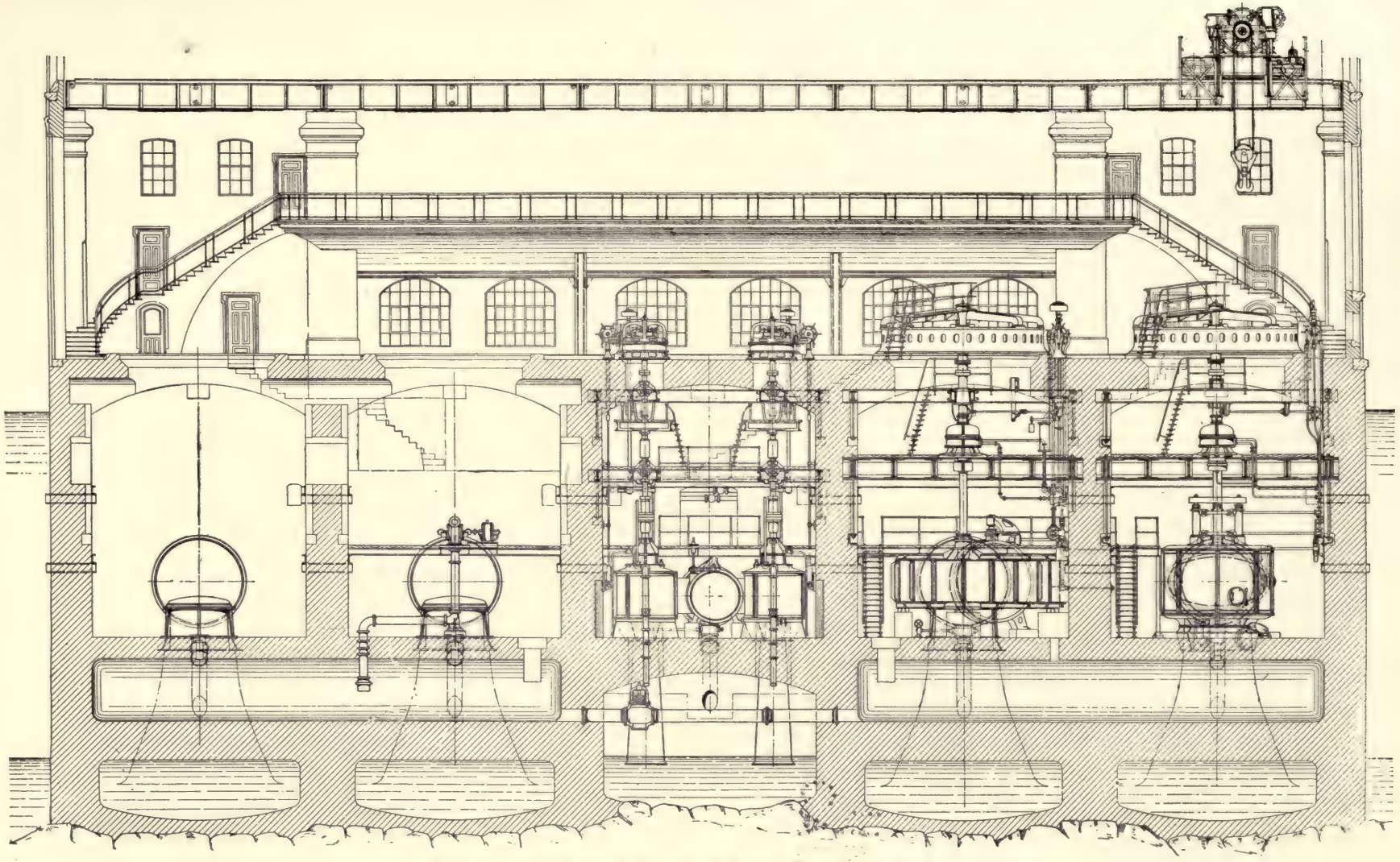


FIG. 3.—Longitudinal Section of Kykkelsrud Plant, Norway.

330 feet wide. The penstocks leave the forebay at right angles, and are provided with fine screens and sluice gates. The gates are operated from the top of the forebay wall, where also the cleaning of the racks is accomplished. As the forebay wall is only 45 feet away from the rear wall of the power house, the penstocks have a short run, being only 100 feet long.

Power House. The power house was originally designed to accommodate four main turbine units and two exciter units. The general arrangement consists of a generating room 150 feet long and 50 feet wide, set directly over the turbine pits, which are 25 feet wide and 15 feet deep. Behind the generating room is the transformer and switching room; the transformer room floor is about 5 feet below the main generating room floor. The switchboard gallery is 16.5 feet above the main generating room floor.



FIG. 4.—Power Plant, Kykkelsrud, Norway.

In the middle of the rear, adjoining the transformer room and beneath the street level, is the pump room.

The arrangement of the windows, pilasters and location of generating units is symmetrical. There are five bays, the middle one containing two 280-HP. exciter units and the controlling switchboards. On each side of the middle section are two generators. The entire interior is finished off in light color, the floor finished with diamond-shaped tile. The generating room is provided with abundant light and ventilation.

Turbines. Owing to the great fluctuation in the water level (the head varies from 40 to 64 feet), it was decided to use inclosed Francis turbines. Of the first installation, one main and two exciter turbines were furnished by Voith, Heidemheim, while the other main unit was furnished by Escher Wyss, Zürich. The Voith 3000-HP.

turbine was designed for a head varying from 52 to 62 feet and consuming from 670 to 530 cubic feet per second, and running with a speed of 150 R.P.M.

The water is fed to the turbine with a velocity of 9 feet per second through a 9.8-foot penstock embedded in concrete. Where the penstock joins the turbine casing, there is an 8.5-foot hand-operated geared butterfly valve. The turbine casing is rectangular and built of structural steel. The inlet of the spiral casing is 6.5 by 3.4 feet, thus giving a velocity to the water of 9 feet per second. The velocity of the water at discharge is 3.9 feet per second.



FIG. 5.—Headrace, Kykkelsrud Plant, Norway.

The vertical shaft of the turbine is 12 inches in diameter and about 25 feet long; on top of this is coupled the shaft of the generator. The weight of the revolving part is 32 tons and is taken up in a step-bearing running under an oil pressure of 220 pounds per square inch. The regulation of the turbines is accomplished by an hydraulically operated governor and works in conjunction with the oil pressure in the step bearing.

The principal difference between the Escher Wyss and the Voith turbine is that the former has a cylindrical casing and vertical moving ring-gates, while the latter has a spiral turbine casing with a so-called clam-shell gate. The penstock connections and butterfly valves are the same. The cylindrical gate is operated by a three-piston arrangement, worked by oil pressure controlled by the hydraulic governor. This governor is similar to that of the Voith turbine and is operated by gearing from

the main shaft. The guarantee of the main turbines, from their manufacturers, under a head of 52.5 feet, is 75 per cent at normal speed, 150 R.P.M. Keeping the speed constant, and a head variation of 6.5 feet up or down, the guarantee efficiency is 72 per cent.

The oil pressure for the turbines is supplied by two motor-driven pumps provided with air chambers to maintain uniform pressure. Each pump has a capacity

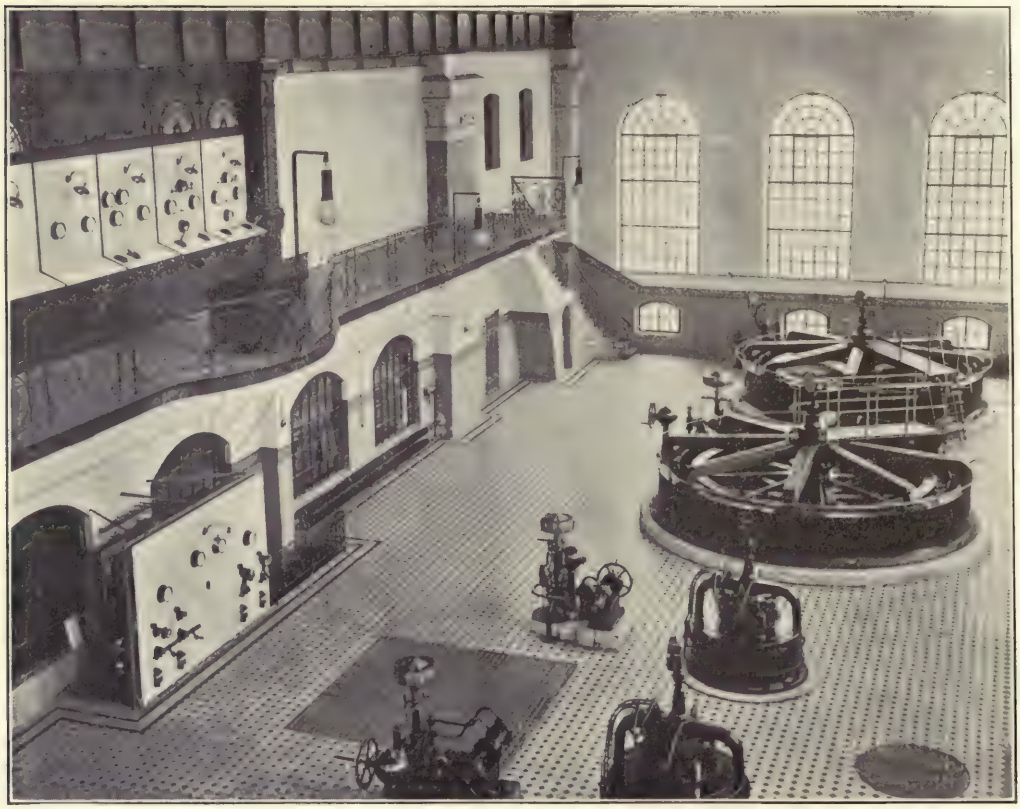


FIG. 6.—Interior of Kykkelsrud Plant, Norway.

of 90 gallons per minute; under ordinary conditions, only one pump is in operation. If one pump is out of commission, the other starts up automatically.

The two recently installed turbines are of the same type as the above described, but have a capacity of 3750 HP. each.

Exciter Units. The two exciter turbines are located in one wheel pit and are supplied by one 6.5-foot penstock. The branches to the turbines are 4.1 feet in diameter and are fitted with butterfly valves. The guarantee of these turbines under a head of 52.5 feet, is 76 per cent running at a speed of 325 R.P.M., the water consumption being 60.8 cubic feet per minute. These turbines are not supplied with oil pressure step bearings, because the oil pressure pumps are driven by current from

the exciters. The weight of the revolving part of the turbines is taken up by relief disks in the turbine casing.

The generator shaft is coupled directly to the turbine shaft. The exciter is wound for 115 volts, 1580 amperes, giving 181.7 K.W. They also supply the station with light, besides running the oil pressure pumps.



FIG. 7.—View in Rear of Switchboard, Kykkelsrud Plant, Norway.

Generators. The main generators of the first equipment are 5000-volt, 3-phase, 50-cycle, 40-pole revolving field type and have a 2000-K.W. capacity. A full load test was run continuously for 48 hours, and no part showed a temperature greater than 26° C. With unity power factor, the efficiency was 96 per cent, and with power factor 0.80 the efficiency was 94.8. The copper loss was 31 K.W.; the iron loss with unity power factor was 16 K.W.; with power factor 0.80, was 21 K.W. The friction and windage loss was 59 K.W.; this included all friction losses in turbine and shaft. The excitation at full load is 290 amperes.

The two recently installed generators are of the same type and make (Siemens Schuckert Werke) as the above, and have a capacity of 2500 K.W.

Switchboard Room. The switchboard is provided for four generator panels, and two panels for outgoing feeders located on a gallery 16.5 feet above the main floor; the exciter switchboard is located on the main floor directly below this gallery.

Each generator panel has a voltmeter, ammeter, synchroscope and phase lamps. The lower front part of the switchboard has hand wheels for controlling the exciter current. The panel for the 20,000-volt outgoing feeders has instruments and levers for oil switches controlling the current. As there are two complete bus-bar systems,

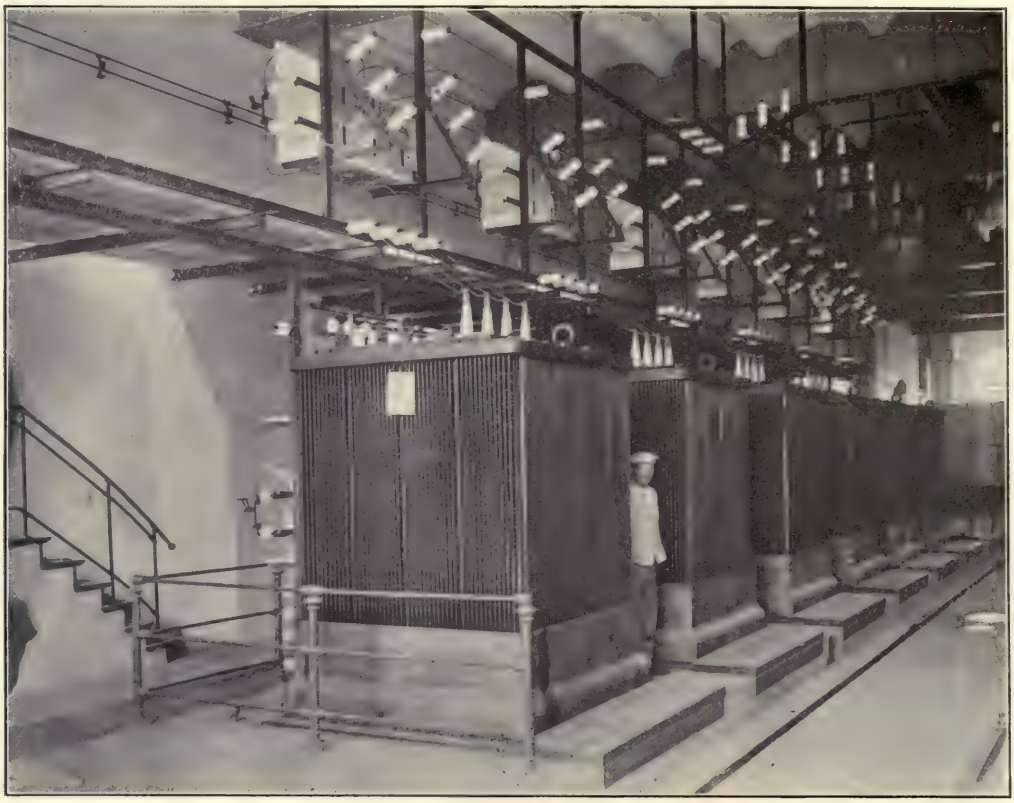


FIG. 8.—Transformer Room, Kykkelsrud Plant, Norway.

current may be thrown on or drawn from either. These bus bars as well as all 5000-volt apparatus are mounted upon a structural steel frame, located five feet in the rear of the switchboard, thus giving a passage for inspection and repairs. The oil switches are mounted upon the top of this framework and are operated by levers (see Fig. 7).

The current from the generators passes through fuses placed in marble compartments. There are three transformers for each generator of the first equipment and they are located in the basement of the switchroom. They are arranged in two banks on either side of a track used for the removal of the transformers, which are of the air-

cooled oil type, 950 K. W. each, and step up the voltage from 5000 to 20,000. The transformer tanks are surrounded by a corrugated iron casing. The air for cooling comes up from the basement beneath, under a pressure of three-fourths of an inch.

The transformer losses for full load at unity power factor are 19.75 K.W. composed of 8.25 K.W. iron and 11.5 K.W. copper loss. With power factor unity from half to full load, the efficiency is constant, 98 per cent. For continuous full load, the temperature of the transformer oil never exceeds 40° C.

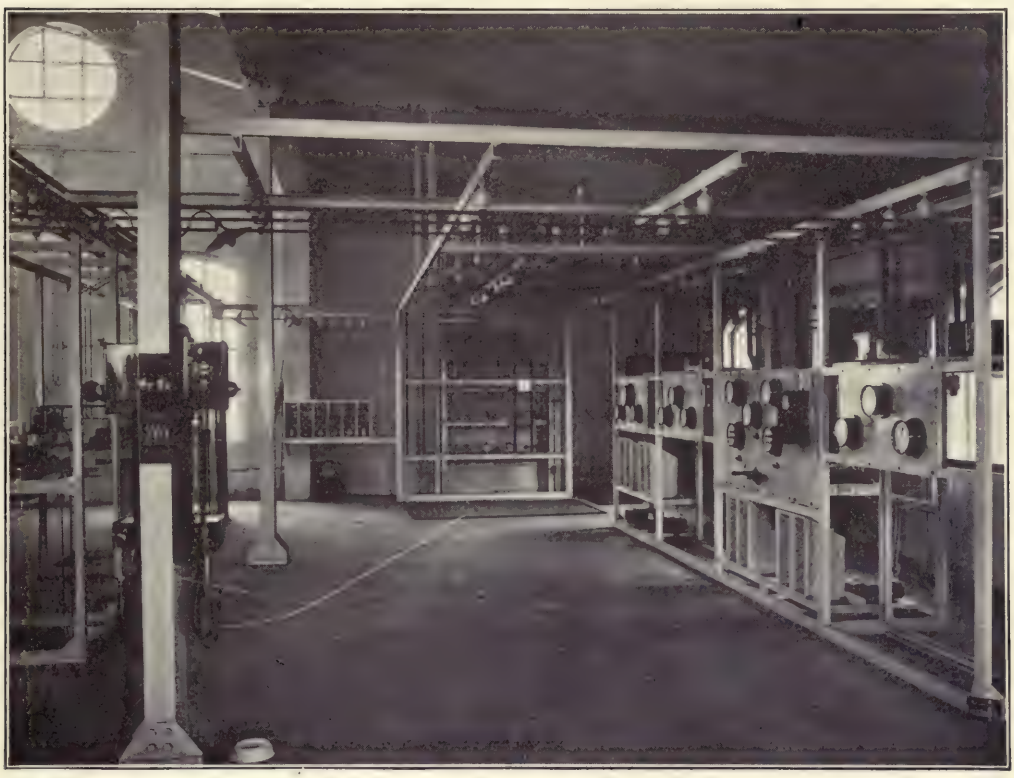


FIG. 9.—Interior of Substation at Hafslund, Norway.

Leads from the transformer go to the high-tension busses located in a structural steel frame on the same floor as the 5000-volt busses. With the extension of the plant, four 3-phase transformers of 2250-K.V.A. capacity each, have been installed. They are of the water-cooled oil type and wound for 5000/50,000-volt transformation, and serve exclusively the transmission line to Hafslund.

Transmission Line. From the Kykkelsrud power house, lead 20,000-volt, 3-phase transmission lines toward Christiana, then around Christiana Fjord to Slemmestad, where the last substation is located. Each cable has a cross section

of 50 square mm. for a distance of 38 miles, then it is reduced to 35 square mm. which runs for 15 miles; the total length of the line is 53 miles. There are seven substations along the line, stepping down the line voltage to 5000 for local distribution.

The lines are carried on wooden poles except at railroad crossings and turns, where structural steel poles are used. This line was put into operation in 1903. In 1907 with additional plant equipment, a 50,000-volt line was run 25 miles southward to assist the plant at Hafslund.

This line is also run on wooden poles except at railroad crossings and turns where structural steel towers are used. As seen in Fig. 10, the steel towers have a close spacing, and in addition, the tops of same are provided with triangular steel frames, which ground the line in case of a break. These precautions were required by the Public Service Commission. The wooden poles are about 40 feet long and stick



FIG. 10.—50,000-volt Transmission Line, Kykkelsrud to Hafslund, Norway.

about 6 feet in the ground. They are spaced about 100 feet apart. The cables have a cross section of 64 square mm. and are carried on porcelain insulators arranged in triangular form, 5.5 feet on a leg; the cross arm is of steel. The insulators are fastened to the pin by hemp and shellac. At present there is only one 50,000-volt line; a duplicate one is projected to run parallel about 35 feet from it.

Substation. The substation at Hafslund is equipped with four 2000-K.V.A. transformers of the water-cooled oil type, and are designed for 45,000/5000-volt step-down transformation. This station is used for a distributing center for the power from Kykkelsrud as well as the power from the Hafslund power house. The 50,000-volt line is protected in this station by water flow grounders, choke coils placed in layers, and a series of horn lightning arresters; there are also used in connection with these several oil resistances. In addition to this, the line on both sides is protected by horn lightning arresters with exceptionally large gaps.

From the power plant at Hafslund, lead four circuits of 5000 volts into the substation. From here, the power from Kykkelsrud and Hafslund may be distributed separately, or, as in common practice, in parallel. The early equipment of the plants and transmission system was furnished by the Schuckert Company, Nuremburg, and the later equipment, by the Siemens-Schuckert Werke, Berlin.

HYDROELECTRIC PLANT, URFTTALSPERRE, GERMANY.[1]

Forced to husband natural resources, particularly coal, advantage has been taken of all kinds of water resources. The continent of Europe, for a number of years, has harnessed the yearly supply of the drainage area of low mountainous or hilly countries.

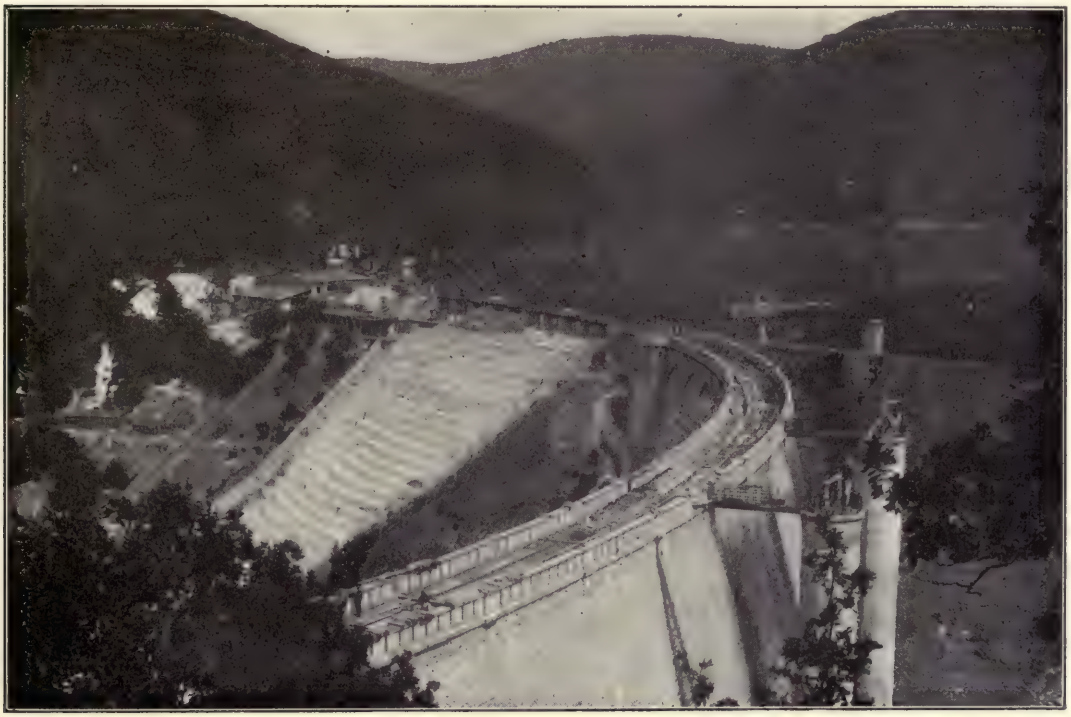


FIG. 1.—Urfttalsperre Dam, showing Valve Chamber Shafts and Spillway.

In order to provide for a steady water supply for the whole year, more particularly for the dry season, large dams have been built across valleys. Having once stored such large bodies of water, the generation of electricity and the transmission by high-tension lines is the next step. Such water resources are usually located away from centers of industry, and it is but natural that advantage will be taken of modern

[1] Reprint of author's article, "The Urfttal Hydro-electric Development in Germany," *The Engineering Record*, Sept. 19, 1908. Based on Data submitted by the Designing and Constructing Engineers.

high-tension distribution. The following is a brief description of the most prominent one of this kind in Europe.

It has a storage capacity of sixteen hundred million cubic feet and a transmission system of 35,000 volts. This plant is known as the "Urfttalsperre," [1] and is situated on the river Urft in the Eifel Mountains, Germany. The capital of $2,000,000 was subscribed by seven cities and districts, four of which supplied one-fifth each; the remaining fifth was supplied by the other towns. The former are entitled to draw power, and the other three are not.

The plant is capable of developing twenty-two million K.W. hours per year, of which sixteen million has already been contracted, giving a yearly income of $165,000.

Dam. About 2.5 miles above the junction of the Urft and Rur, is located a dam, establishing a drainage area of 145 square miles. This dam is 190 feet high, having a width at the bottom of 165 feet, and at the top, 17 feet. The dam was built in arch form, with a radius of 650 feet, giving the crown a total length of about 1000 feet, about 300 feet of which is used for spillway, the water flowing over in cascade.

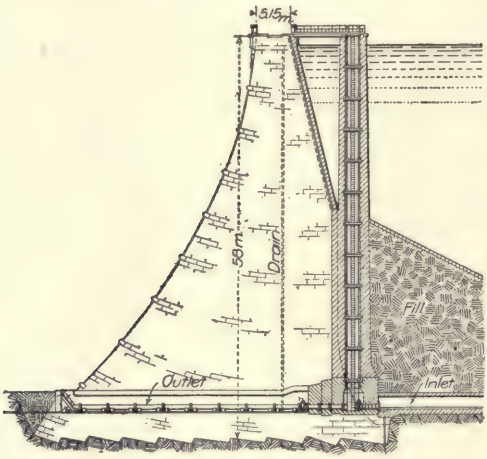


FIG. 2.—Section through Dam and Valve Chamber, Urfttalsperre Plant, Germany.

The dam itself is made up of cyclopean masonry, the largest of the stones being of a size which required to be handled by two men. Both sides of the dam are faced with rough-faced cut stone. The dam was built in one continuous mass, for which purpose, three timber towers were erected for elevating the material. From these towers, tracks ran across the dam, and by means of turntables the cars were placed on longitudinal tracks. The mortar is composed of lime, sand and trass. Cement was not used, because it was feared the cement would harden too quickly and unequally throughout the mass, thus producing unequal stresses. Trass has of late years been much used in German dam construction, as it forms, when mixed with lime and sand, a hard and impervious substance which dries slowly and equally.

The cross section of the dam will be seen in Fig. 2. For the purpose of draining the storage basin, two discharge pipes are led through tunnels, through the bottom of the dam. The gates are located on the upstream side in valve chambers at the bottom of a shaft extending above the high-water level. The tops of the shafts and crown of dam are connected by bridges to facilitate the operation of the gates.

The upstream side of the dam is plastered with "Siderosthen," a waterproof material, then faced with tile. To drain off the seepage, the dam is provided with vertical seepage drains.

Headrace. The power plant itself is located at Heimbach on the Rur, 1.7 miles away from the dam, so that at low water it has a head of 230 feet, and at high water, 360 feet. A tunnel 8850 feet long, having an area of 60 square feet, is cut through the mountains, thus connecting the collecting basin with the penstocks.

On the basin side of the tunnel is located a sluice gate operated through a vertical shaft about 150 feet high. On the other side of the mountain, at the junction of penstock and tunnel, is located an equalizing shaft which has on the top a reservoir that absorbs all fluctuations in the water flow. This chamber performs the same duty as a standpipe on a penstock, but in this case no water is wasted. From this shaft are also operated the sluice gates controlling the water supply in each of two penstocks. The velocity of the water in the tunnel is six and a half feet per second.

From the bottom of the equalizer shaft, run horizontally two penstocks parallel to the slope of the mountain, from whence they run to the power house. The upper portions of the penstocks run through tunnels and are partly embedded in concrete, and covered with filling to protect the penstock from loose boulders.

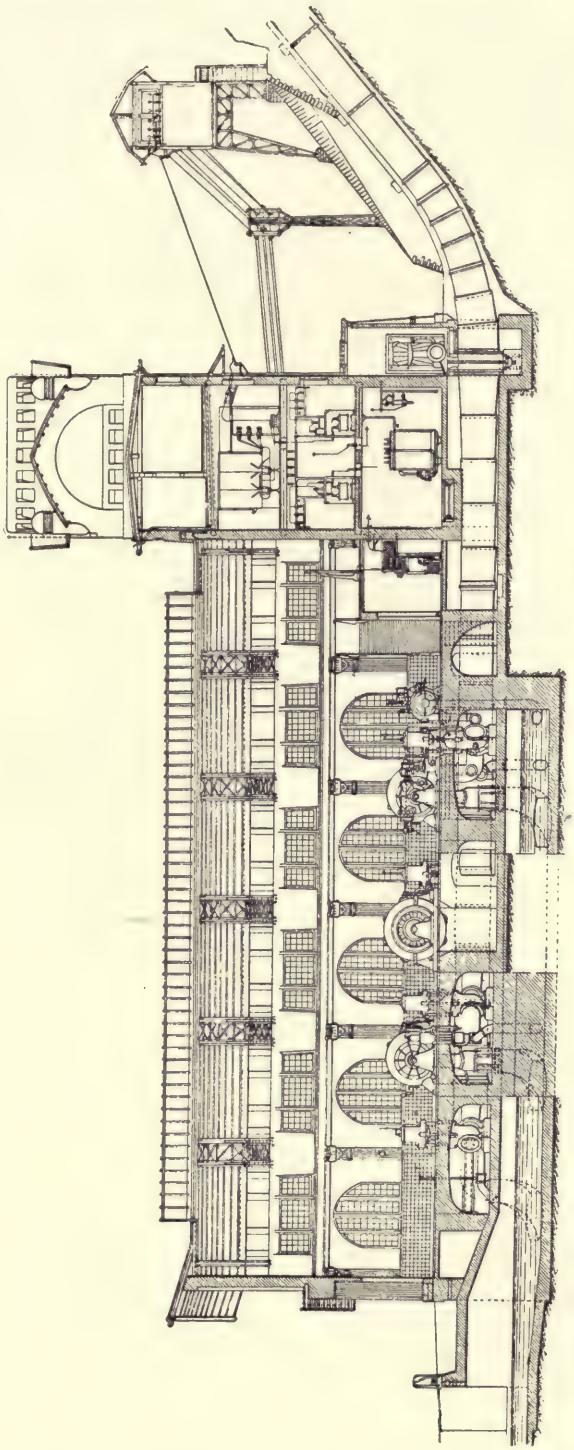


FIG. 3.—Longitudinal Section of the Urfttalsperre Plant at Heimbach, Germany.

Power House. The power house consists of the generating room, switching and transformer room; on each side of the switching room are two wing towers for offices, repair shops, etc. As will be seen from the accompanying illustrations, the interior

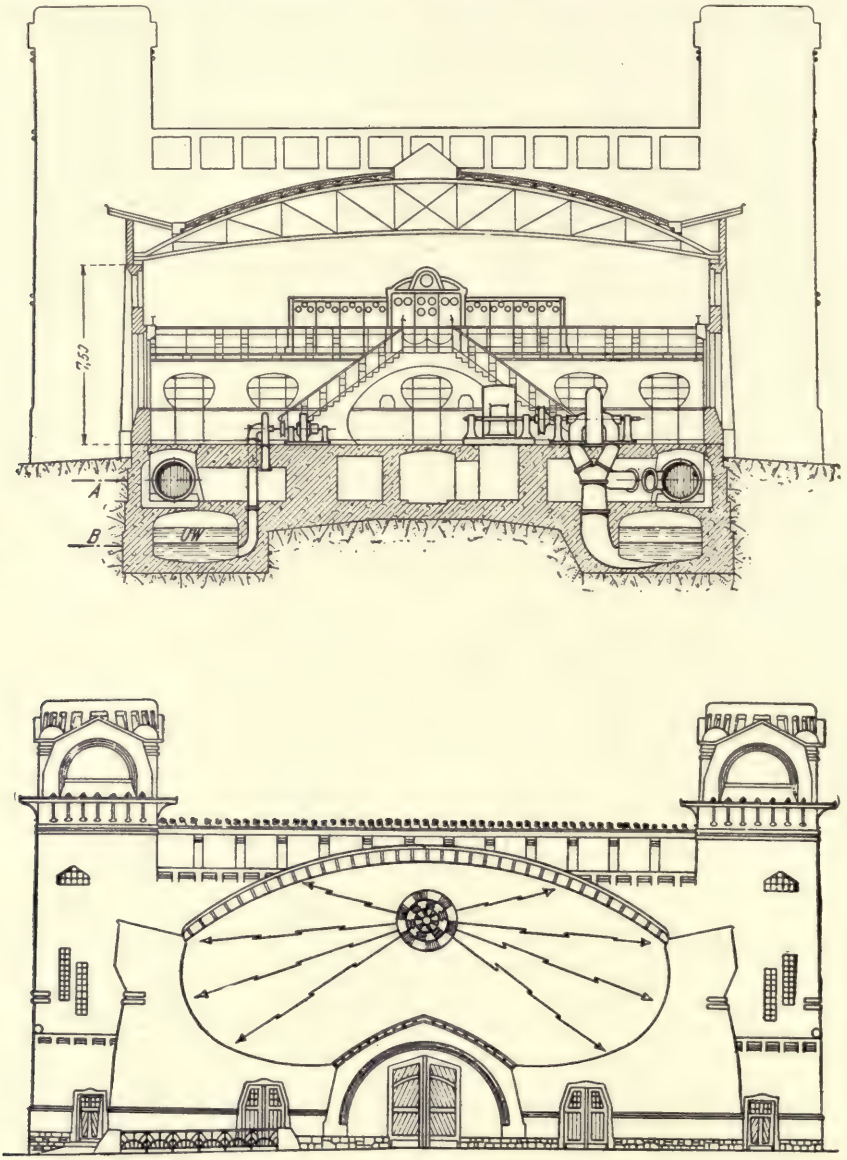


FIG. 4.—Cross Section and End View of the Urfttalsperre Plant at Heimbach, Germany.

and exterior are of the most artistic and modern design. The generating room is 95 feet long by 75 feet wide; the switching room is 75 feet long and 30 feet wide. The substructure up to the floor line of the generating room is of concrete, while the walls are of brick covered with stucco. The roof trusses are of structural steel and placed in pairs; the top and bottom chords are curved.

The roof itself is of Schwemmstein (special brick of volcanic origin) covered with wood cement (cement mixed with rough sawdust).

The turbines are arranged in two parallel rows, the generators facing each other. The ultimate equipment will consist of eight units, but at present there are only six installed and two exciters. The penstocks before entering the power house are provided with hydraulically operated butterfly valves, and the branches to the turbines with hydraulically operated gate valves. At the end of the penstocks are manholes, and provision is made for drainage.

Turbines and Generators. The turbines are of the double-flow horizontal Francis type, as manufactured by Escher Wyss & Co., Zurich. They are designed to develop for minimum head of 230 feet, 1550 HP., and for a maximum head of 360 feet, 2000 HP. at 500 R.P.M. The casing is of cast iron; the water is fed in from the circumference and discharges through two draft tubes which eventually unite. Since there are two draft tubes, the runner is provided with a right and left hand set

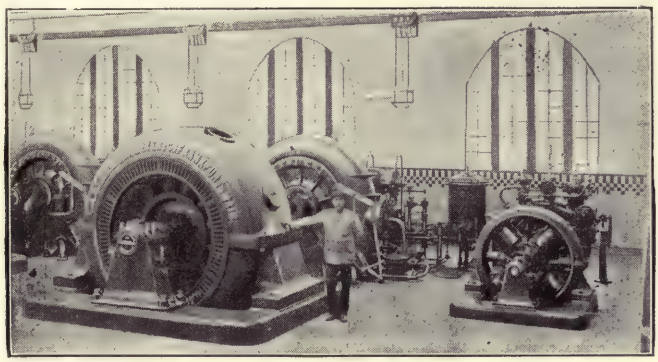


FIG. 5.—Main and Exciter Units, Urfttalsperre Plant, Germany.

of buckets. The single gate-ring is connected to two hydraulic governors, automatically operated. In case of a sudden rise of pressure, a portion of the water is by-passed by the governor into the tailrace until normal pressure is established.

The bearings are oil and water cooled, the water being taken from the penstock. One of the bearings is a thrust bearing. Each turbine is provided with a tachometer, manometer and two vacuum meters, also two cocks, one for releasing air, the other for drainage.

There are two exciter turbines of 200 HP. each, running 900 R.P.M. They are of the same type and manufacture as the above described, and are automatically and hand controlled, similarly to the main turbines. The turbines are connected to the generators by Zodel insulated flexible couplings.

The main generators, of Siemens-Schuckert Werke, Berlin, are designed for 1370 K.W., 3-phase, 50 cycles, 5000 volts, and power factor of 0.85. The exciters are 135-K.W., 225-volt capacity. In testing the units for maximum capacity by suddenly throwing on or off 200 K.W., the speed variation was observed to be 2.5 per cent.

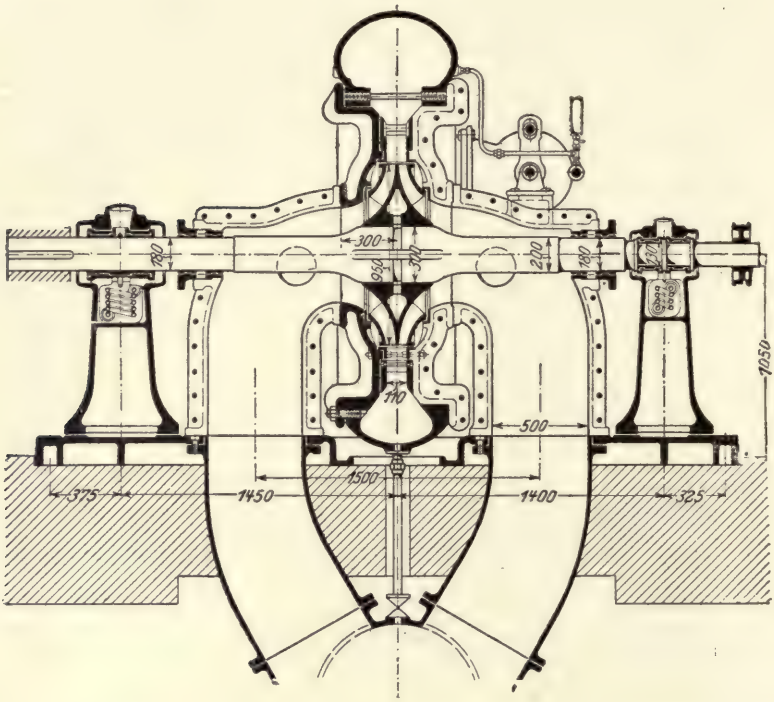


FIG. 6.—Cross Section of Turbine, Urfttalsperre Plant, Heimbach, Germany.

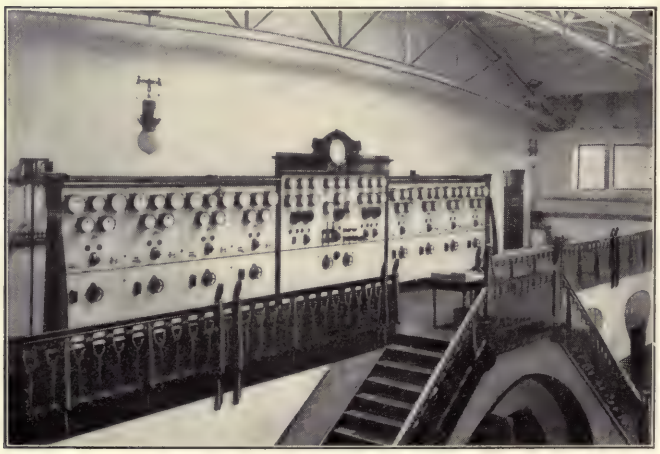


FIG. 7.—Switchboard, Urfttalsperre Plant, Heimbach, Germany.

Switching Room. The generator voltage is stepped up to 34,000 volts through its own transformer, there being no 5000-volt bus-bar system. The secondary leads of the transformers are connected in ring system (practically not used in the United States). Between all junctions of the transformers and outgoing feeders are located sectionalizing switches. Transformer and outgoing feeders are provided with automatic oil switches. Upon first glance at the illustration,[1] it is seen that the ring system affords a complete protection against line surges; this is obtained at the sacrifice of flexibility of operation; thus when one transformer is dead, the generator

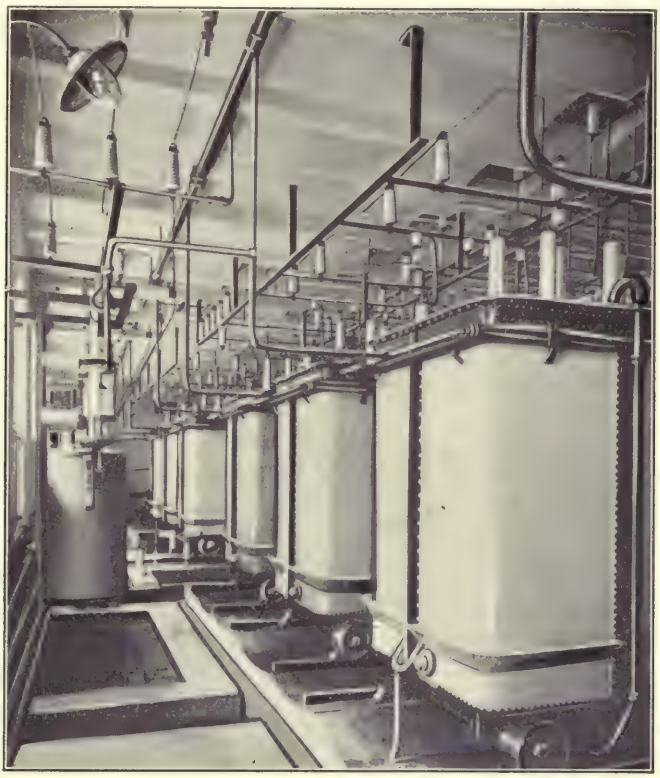


FIG. 8.—Transformers and Water Flow Grounder (at the Left), Urfttalsperre Plant, Germany.

is idle. This system is used principally as a protection for the transformer. Between generators and transformers are fuses, while between transformers and the ring system are remote control automatic oil switches.

The outgoing feeders, of which there are five, are protected by the same type of oil switches and three-pole sectionalizing switches. Between the sectionalizing and oil switches are choke coils and connections to lightning arresters which are of the Siemens-Schuckert horn type.

For further protection, there are water rheostats and continuous flow grounders connected to the ring system, thus providing a good ground connection. About

[1] (See Chapter on Bus Bars.)

one-tenth of an ampere escapes continuously through this grounded connection. Small and gradually rising overloads are readily grounded by this device. The water stream is 20 inches long and has a cross section of two square centimeters.

At one end, about 11 feet above the floor of the generating room, the switchboard is mounted on a mezzanine floor, from which the whole plant is controlled. The switchboard is of artistic design, consisting of three central panels and four wing



FIG. 9.—35,000-volt Bus Bar and Oil Switch Room. Urfttalsperre Plant, Germany.

panels on either side. The framework is of structural steel, and the panels of white marble. Each of the wing panels contains the necessary instruments for controlling one generator. The three central panels contain the totalizing meters and master control switches.

The transformers, of which there are at present six, are located in the switching room on the same floor level as the generators; the ultimate capacity is eight. The transformers are of the three-phase type, and are arranged in a single row in front of

which is a track pit, so that they can be readily removed when necessary. Above the transformer room is the 35,000-volt oil switching room. The switches are arranged in two rows; they are of the remote motor control type. On the top floor are located the lightning arresters and outgoing feeders.

Transmission Line. The plant is provided for five outgoing feeders; at present only four are installed. The longest line is 38.5 miles; the others are 24, 16 and 21 miles. The three former have a cross section of 50 square mm.; the latter, 20 square mm. At present, ten miles of the latter are operated at only 5000 volts, although designed for 35,000 volts.

The poles for the transmission line are built up of structural steel, either of two channels and lattice work construction, or angle iron and lattice work, and are set in concrete blocks.

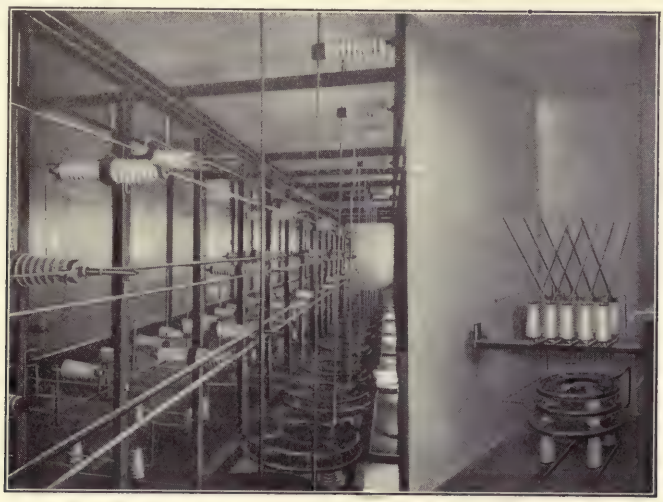


FIG. 10.—Protecting Devices for Outgoing Feeders, Urfttalsperre Plant, Germany.

They are designed to carry high tension (35,000) or low tension (5000) alone or both together. The high-tension lines are 31.5 inches apart on a leg and 16 inches away from the iron pole. The lines are carried on triple petticoat insulators mounted on steel pins fastened to wooden vertical or horizontal cross-arms.

In most cases, the lines skirt the towns and cities, and run along the main highways wherever possible. Inasmuch as these lines have to cross many streets, railways, telephone and telegraph lines, great precaution had to be exercised.

In many cases, the public service commission demanded that the guard wires be carried on separate structures or poles.

Substations. There are two kinds of substations known as "A" and "B." Substations "A" step down the line voltage (35,000) to 5000, the other, "B," from 5000 to 225.

Substations "A," of which there are sixteen, are of two-story masonry construction. The feeders go in and out the top story, where all the high-tension switching and testing apparatus are located.

The lower floor contains the low-tension apparatus and transformers. Each station is designed to accommodate two 100-K.W. transformers, and is built on a standard system. The station is well provided with switches and safety devices, so that if a switch or transformer is out of commission, the service is not necessarily



FIG. 11.—Type of Transmission House in Front Tower with Section Switch.

interrupted. In connection with some of the "A" stations, living houses are provided, so that if the patrolman is out on his beat, any telephone communication from the power house or other substations may be received by attendants.

The 5000-volt lines, for the greater part, are carried on wooden poles, set in concrete blocks. In some sections, where it was not advisable to carry the 5000-volt

lines overhead to the stations, they are run underground. Where the lines go underground, they go down a lattice-girder steel pole provided with lightning arresters and choke coils.

The "B" or low-tension substations are for the most part built on a standard system, except in some cases, where the consumer builds his own substation.

It might be of interest to state that the German government investigated the effect the 35,000-volt alternating current transmission line has on its long-distance telephone system.

There was a certain telephone trunk line, much influenced by the high-tension alternating current. The investigation [1] proved that the transmission line, 2600 feet away from the telephone line, still affected that particular trunk line, while other lines closer to same were unaffected.

Financial Aspects. The complete hydroelectric transmission system, including high and low tension lines, cost approximately $2,500,000, of which, the dam cost $1,000,000. The latter item is small in comparison with similar plants. Dams of this character, although primarily built for water power developments, serve also to prevent floods in certain seasons. Comparing the cost of same per cubic foot of water imponded, with dams of similar plants, the following figures are submitted.

Urfttal, 0.06 cent; Remscheid, 0.38 cent; Barmen, 0.57 cent; Nonsdorf, 1.21 cents, which gives an average cost of 0.55 cent per cubic foot of water imponded.

When a consumer is supplied with current for power from the 5000-volt line directly 0.9 to 1.0 cent is charged per K.W. hour, provided he furnishes his own transformer equipment, otherwise the charge is 1.5 to 6 cents per K.W. hour, depending on the amount of power consumed. If current is supplied from the 225-volt distribution system, the price varies, with a maximum of 8.5 cents. When the consumer guarantees a certain amount of yearly power, there is a rebate of 30 per cent.

All current for light, irrespective of the amount, drawn from 225-volt circuit, is supplied at 10 cents per K.W. hour for the first 5000 K.W. hours; above this 8 cents is charged; and when drawn from the 5000-volt circuit, there is a rebate of 20 per cent.

Although the plant has not yet reached its full capacity, the returns on the money invested already amount to 4 per cent.

UPPENBORN PLANT AND ITS 50,000-VOLT TRANSMISSION SYSTEM, MUNICH, GERMANY.[2]

To supply the city of Munich with additional electrical energy, and to run in parallel with the several existing municipal steam and hydraulic plants, a new municipal hydroelectric plant has recently been completed.

It utilizes the water of the river Isar in Moosburg, where three 1887-H.P., double twin turbines are installed. Energy is generated at 5000 volts, but the E.M.F. is

[1] Die Hochspannungs-Kraftübertragung an der Urfttalsperre, by O. Brauns. *Elektrotechnische Zeitschrift*, April 9, 1908.

[2] "Das Uppenbornkraftwerk," by S. Meyer, H. Niesz and K. Dantscher. "Electrische Kraftbetriche und Bahnen," Nos. 16, 17, 18, 19 and 20, 1908. See also "*Electrical World*" Nov. 28, 1908. "German 50,000 Volt Transmission System."

increased to 50,000 volts for transmission over two parallel circuits to the substation near the city of Munich, where the E.M.F. is decreased to 5000 volts for distribution.

This plant, known as the Uppenborn station, being the latest of German hydroelectric undertakings, possesses many novel features, particularly on the electrical end.

Thirty-three miles below the city of Munich the river Isar makes a bend, which is cut off by a head and tail race canal about 2.5 miles in length, having a net fall of 28.1 feet at low water and 24.8 feet at high water. Permission was given to draw 2500 cubic feet of water per second during 207 days, while during the remainder, including the dry season, only 1070 cubic feet is available.

Headrace. Just below the junction of the headrace and the river, a dam was thrown across the river at about right angles. For this purpose the width of the Isar was increased from 225 feet to 619 feet. On the opposite end from the intake is a



FIG. 1.—Power House, Uppenborn, Germany.

spillway 328 feet long. Adjoining the spillway is a fish passage 6.5 feet wide, built up in steps. Next to this are the sluice gates for regulating the head. They are divided into four sections, each 55.7 feet wide, three of which are separated by concrete pilasters, while the fourth is separated by a lock 26.25 feet wide for passing boats, etc. This lock, having two mechanically operating swinging gates on the upstream end, is about 150 feet long. The bottom has a slope of about 2 per cent. It is made of concrete faced with planking.

The sluice gate passages adjoining the lock are subdivided into two sections by a removable guide, for the purpose of giving free passage for floating débris, etc. The two passages near the intake are divided into three sections, and the guides here, for the sluice gates, are stationary.

Each sluice gate is divided into two sections, one upper and one lower. They are, however, not of the same size, the lower being the smaller, thus enabling the sections, due to the hydrostatic head, to be operated by the same amount of power.

Two such sections, or one gate, can be lifted by a 3-phase, 10-HP. motor in ten minutes. When operated by a hand windlass with a ratio of 1: 2800, 50 minutes are required to lift one section. On the down-stream side of the gates resting on the concrete piers, is an operating gallery of structural steel.

The bottom of the intake to the headrace is about 7 feet above the bed of the river, thus preventing foreign material, such as gravel and sand, from entering the headrace. As the provision cuts down the depth of the water to 4.9 feet, the width of the intake was made 125 feet, thus giving a velocity of 3.9 feet with a friction or head of loss of 4 inches.

This intake passage is divided by a massive concrete pier, and in order to further reduce the size of the sluice gates they are subdivided into four sections by structural steel sluice guides. Each gate is divided in two parts and operated in the same manner as those described above.

At the side of the dam and intake is an attendant's house, which contains a transformer for supplying energy to gate motors. On the other side of the intake is a lock, similar to the one mentioned, for passing boats into the headrace.

The headrace canal is 1.3 miles long, and is built with a slope of 1 in 3000 for a calculated velocity of 4 feet per second. It is 54.5 feet wide on the bottom, with sideslopes of 1 to 1.5. Under ordinary conditions the depth of the water is 9.2 feet. Throughout the greater part, the sides of the canal are finished off in embankments, which, at the highest point, are 16.5 feet above the natural ground.

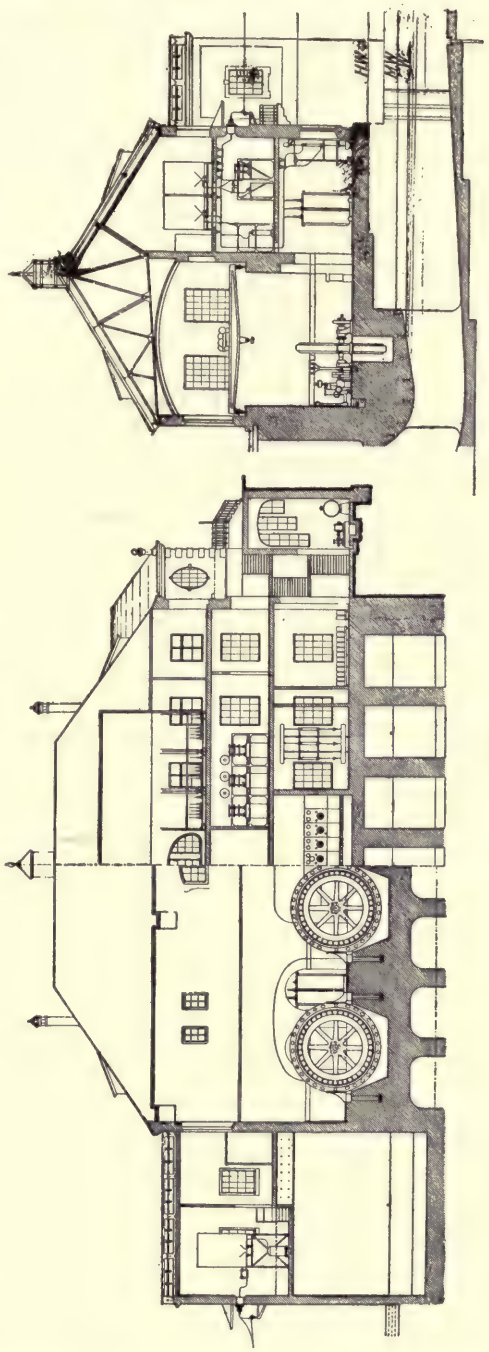


FIG. 2.—Longitudinal and Cross Section of Uppenborn Power Plant, Germany.

At a low point the headrace crosses a creek which is passed underneath through two culverts.

Generating Plant. The power house lies across and at right angles to the headrace, which is here 175 feet wide. At one end of the power house is a lock for passing boats and a fish way, similar to those at the dam. At the other end is a sluice gate and passage for letting off the headrace water into the tailrace; the latter is 1.1 miles long. Some difficulty was encountered during the excavating, because part of the work runs through marshy land.

The generating and switching rooms are housed under a common roof. The former is 103.3 feet long and 26 feet wide. In order to give the generating room a pleasing appearance, a ferro-arched ceiling is built up under the roof truss, 38 feet above the floor level. The whole room is kept in light color, and well illuminated. The floor and wainscoting are tiled.

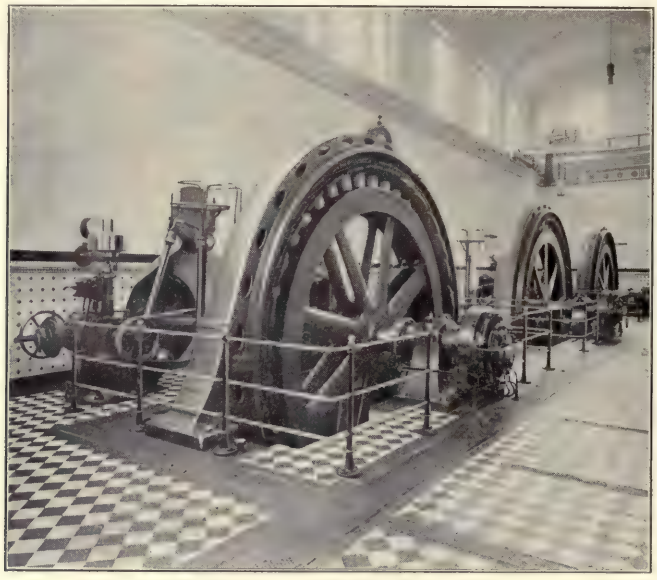


FIG. 3.—Interior of Generator Room, Uppenborn Plant, Germany.

At an angle of 72 degrees to the flow of the water to the turbine chamber, and in front of the sluice gates, are racks built up of 2.25 by 0.25-inch bars, spaced with a clearance of one inch. The sluice gate for each turbine is 11.5 feet high and 24 feet wide, and is divided vertically into three sections, which can be interconnected for motor operation.

The sluice gate seen foremost in Fig. 1 is 14.8 feet high and 13.1 feet wide, and its purpose is for emptying the headrace as above indicated. On the other end of the sluice gates is the gate for the lock; it is 26.25 feet wide and 16 feet high, and is lowered when the water is let off. All sluice gates, with the exception of the latter, can be motor operated. On the downstream side of the gates is a gallery from which they are operated by hand.

Turbines and Generators. The turbine chambers are located between the gates

A.E.&M.E
UNIV. OF CAL.

and the generating room, the roof being flush with the street and made of reinforced concrete. There are installed three twin inward-flow Voith turbines, mounted on a horizontal shaft, each having an output, with a water consumption of 785 cubic feet and a head of 26 feet, 1887 HP. at 150 R.P.M. Each twin turbine has its own draft tube; the two of a complete unit join into a single draft tube, which is part of the foundation, and discharge into the tailrace.

During the greater part of the year there is surplus water, to utilize which, a 224-HP. twin turbine, consuming 100 cubic feet of water per second, making 300 R.P.M., has been installed. The generator of this turbine is a three-phase, 5000-volt, 50-cycle machine, designed for an output of 210 K.W. at a power factor of 0.9. To the unit there is coupled a 110-volt exciter. The operation of this set is kept independent from the remainder of the plant, as it supplies energy for the city of Moosburg. However, provision is made so that in case of emergency it can be joined in parallel with the rest of the plant, as will be seen below.

The control of each of the main turbine sets is accomplished by an oil-actuated, hydraulic governor, located in the generating room. The oil is supplied at 295-pound pressure by pumps operated from the turbine shafts. The oil piping of the different pumps is interconnected so that one may assist another. For synchronizing the generators, the governors are equipped with small motors, controlled from the main switchboard.

The turbine shafts are rigidly coupled to those of the three-phase alternators, which are of the revolving-field, 5000-volt, 50-cycle type. With unity power factor the output of each generator is 1400 K.W. Overhanging on each shaft is mounted a 17.5-K.W., 110-volt exciter.

To accommodate the type of turbine generator installed, the floor had to be placed about 21 feet below the ground level, which is about 3.5 feet above the high-water level in the tailrace, thus placing the bottom of the generator pit some 6 feet beneath the high-water level. To prevent seepage from entering the generator pits, and also the trenches for the generator leads to the switchboard, they are lined with steel plates. For the same reason, the generator leads are taken off from the upper part of the armature and passed through a column to the trenches leading to the switchboard.

Switch Gear. The three main generators feed energy into one bus-bar system, connected at each end to transformers. Between the junctions are sectionalizing switches, thus keeping the two outgoing lines to Munich entirely separate. All switching is done on the 5000-volt side, there being no high-tension bus-bars.

For each outgoing line there is one three-phase transformer of 2000-K.V.A. rating for increasing the E.M.F. from 5000 to 50,000 volts. They are of the Siemens-Schuckert, oil-insulated, water-circulated type. By using 60 cubic feet of cooling water per hour, with the transformers under full load, the temperature of the oil surface is 95° F. above that of the incoming water. The efficiency at full load is 98 per cent. The ohmic resistance drop is 0.95 per cent, while the impedance drop at full load current is 3.5 per cent.

The secondary windings of the transformers are split up into sections with the

leads brought outside, so that they can be readily changed from star to delta connection for giving a 25,000-volt transformation if desired.

The transformer casings are made of steel plates, and rest on rollers and tracks, whereby they can be shifted to the generating room and there handled by a 16-ton overhead crane for repairs. Each transformer, when filled with oil, weighs 11 tons.

A novel feature connected with the transformer, and of especial value to hydraulic plants, is the utilization of the circulating water of the transformers for heating the various rooms of the plant.

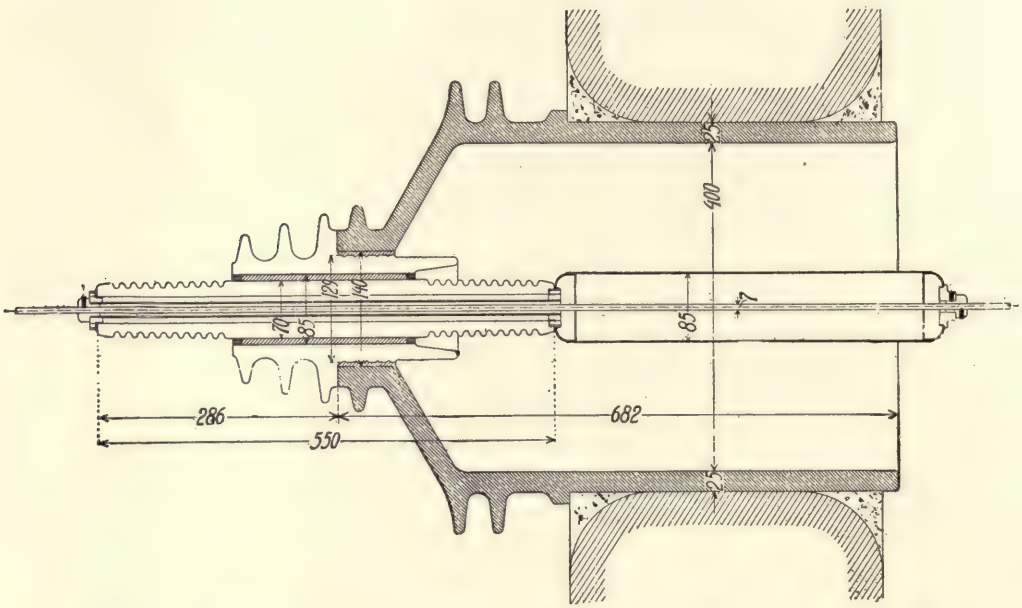


FIG. 4.—Wall Outlet, 50,000-volt Transmission System, Uppenborn, Germany.

The water for cooling the transformers, as well as that for the water flow grounders and for drinking purposes, is supplied by a 5-HP. centrifugal pump, which delivers to an elevated tank. The pump works automatically between the limits of 45 pounds and 75 pounds. Use is made of a 3-HP. auxiliary pump when the cooling water of the transformers is utilized for heating purposes. Another pump removes possible seepage.

In front of the switchboard is a controlling bench from where the generator room is readily overlooked. It contains all levers and wheels on the flat surface, while the instruments are mounted on the incline. From this desk, the attendant starts the turbines by means of the motors on the sluice gates. Moreover the field and speed control, synchronizing as well as loading the generators, is done from this point without the attendant losing sight of the generating room.

The switchboard is made up of several panels, four for generators and three for the outgoing lines. All are of the wagon panel type of the Allgemeine Elektricitäts Gesellschaft, consisting of a small carriage resting on wheels upon the steel framework

of the switchboard. The advantage of the wagon panel system is that the panel with equipment can be readily withdrawn for inspection and repair. The electrical connections are made by copper clips on the back of the carriage, which is done by sliding in the wagon panel. Each generator panel contains an oil switch provided with an overload and reverse current time-limit relay, which can be operated by hand wheel on the panel or by a pilot switch on the controlling bench. The two series transformers for the relays and one for the ammeter are also placed in the carriage, while the switch indicators are located on the controlling bench. There is also a small three-phase transformer for the synchronism indicator and one for the wattmeter; the instruments themselves are placed on the controlling bench.

The individual equipment of the carriages are disconnected by small switches placed in a row on the switchboard front. Each of the transformer panels contains an oil-switch with an excess-current cut-out and a wire break relay; three series transformers; one ammeter and its transformer; one potential transformer, and two dry elements for the wire break relay.

Lightning Protection. In the power house, as well as the substations, there are very extensive systems for protecting against lightning. The equipment in the power house is as follows: For direct lightning strokes there is placed at each phase-lead a horn-gap of nine-sixteenths inch, connected to large water rheostats, located in an annex of the power house. In the upper floor of the switching rooms are four choke coils connected in series, each preceded by a horn gap. Between these and the transformer is a coil known as the generator choke coil, which is also provided with a horn gap. All the gaps for each phase lead (2.25-inch setting) have a common ground. To the grounding device is connected an oil rheostat to prevent the generator current from following the lightning stroke. To take care of light surges, water-flow grounders are installed.

To equalize the pressure between the phases, there are three horn spark-gaps connected in "star" to the middle point of the transformers.

It might be of interest to state that the waterflow grounders are designed to carry off from 0.1 ampere to 0.15 ampere, according to the chemical composition of the water. This means that a three-phase grounder leads off 9 K.W. and the power for four grounders amounts to 36 K.W., which is less than 1 per cent of the power to be transmitted. The water is supplied by two centrifugal pumps.

The horn-gaps, of which there are five per phase, are spaced 8 inches apart, between which are double asbestos partitions 7.8 feet high. As they are located on the upper floor of the switching rooms, the roof and roof-truss over the horn-gap room is lined with cork plates covered with incombustible material.

As stated, the 210-K.V.A. generator, supplying 5000 volts for the city of Moosburg, is, under ordinary conditions, operated independently of the rest of the plant by means of sectionalizing switches in the bus-bars. The energy is conveyed by means of a cable running along the headrace. At the attendant's house, near the dam, a tap is made to feed a 30-K.W., 5000-volt to 110-volt transformer for operating the sluice gates.

Insulators. All station insulators for 50,000 volts are made up of three corrugated cylindrical porcelain sections, held together by a mechanical screw coupling. The height over all is 11.5 inches; the diameter of the lower section is 5.5 inches, and that of the remainder, 3.75 inches. The design is such that the total porcelain thickness between the metal couplings is 2.25 inches, while the surface leakage path is 23 inches. The corrugations have the effect of making the high pressure noticeable by loud, hissing, dark discharges, without measurable loss. These insulators are placed at least 20 inches apart, while those carrying ground connections are spaced not less than 12 inches apart.

The high-tension wall outlets on the main as well as on the substations are of the design seen in Fig. 4. An outlet consists of two concentric corrugated porcelain

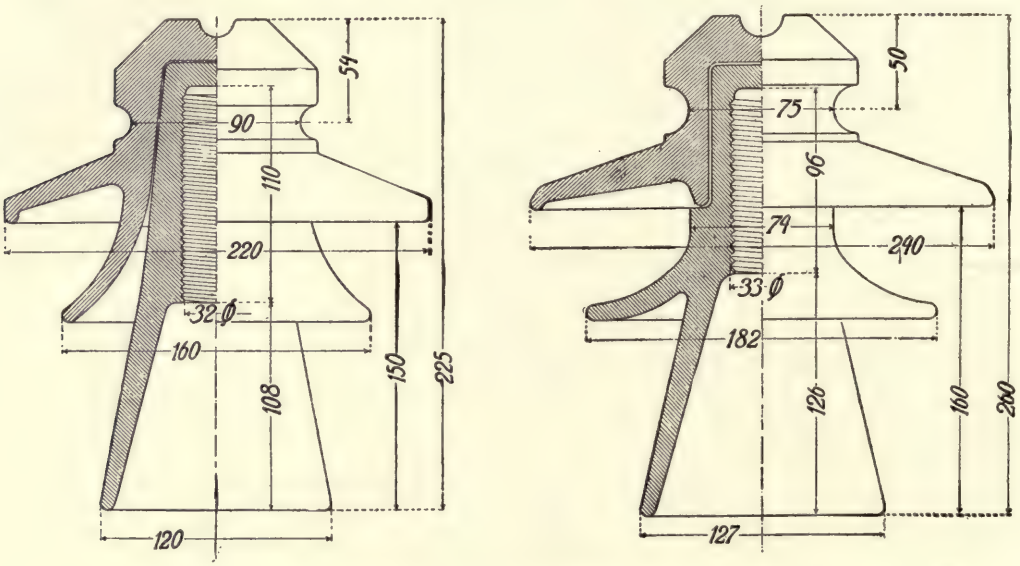


FIG. 5.—Type of Insulators. Uppenborn Transmission System, Germany.

bushings cemented together, which in turn are cemented in the bell-shaped end of a tile cylinder 16 inches in diameter. As the radius of the line conductor is only 3.5 mm., it was thought advisable to increase its diameter artificially by placing a brass tube 85 mm. ($3\frac{3}{8}$ inches), around the conductor, thus cutting down any arcing effects due to brush discharges. Although the distance between line and ground is reduced, the arcing effects are no more noticeable.

Transmission System. The transmission system is 32 miles long, and calculated to transmit 4000 K.W. at 50,000 volts, for which purpose two separate transmission lines were installed. The conductors consist of a seven-strand cable, 16 square mm. in cross section, and spaced 4.6 feet on a leg. Under normal operation both circuits are alive, and under this condition the total resistance drop is about 1100 volts, and the reactance drop 430 volts. The power factor at the power house is 0.95, while at the substation it is unity. This difference is due to the charging current.

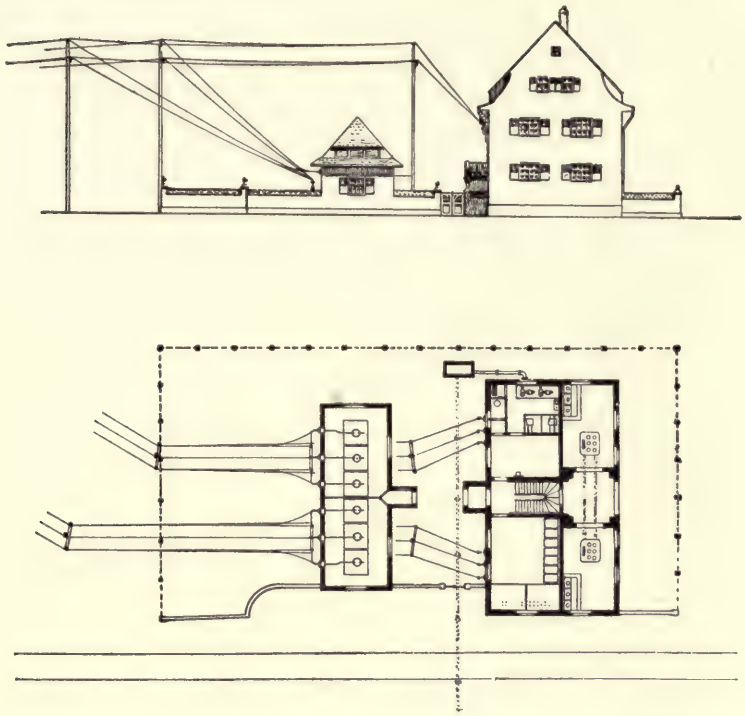


FIG. 6.—Transformer and Lightning Arrester Station Hirschau, Uppenborn Transmission System, Germany.



FIG. 7.—Sub Station Hirschau and Lightning Arrester House, Uppenborn System, Germany.

As will be seen in Fig. 5, there are two different kinds and manufacture of line insulators; both are of the three-petticoat, two-piece type, glazed together in the manufacture. The insulator shown at the right hand is 9 inches high, the head being 8.75 inches in diameter. The other is 10.25 inches high, the head being 9.5 inches in diameter.

Before the contracts for the transmission structures were let, tests were conducted on (1) wooden A-frame structure; (2) steel tube poles; (3) Mannesmann tube poles; (4) latticed tower of angle iron; (5) I-beam A-frame.

The following table gives a comparison of the tests on the above structures, together with the price in marks. The structures are tabulated successively, as above numbered; the data are expressed in the metric system and serve for ready comparison.

	1	2	3	4	5
Safe load in kilograms	100	1800	2200	870	1800
Cost, including two arms, in marks	35.20	40.35	45.20	80.70	40.00

It will be noticed that the wooden structure was not favorable, especially as the line passes through marshes, and the life of a wooden structure is short. The I-beam structure outstripped the others regarding safe load and price, which is the reason why these poles were adopted.

The standard poles are 23 feet high to the lower insulators. The standard spacing is about 165 feet. The two parallel poles are spaced about 13 feet apart; they are embedded in concrete blocks about 5 feet deep. Each pole is made up of two 5.5-inch I-beams; for present conductors, 3.5-inch I-beams would have sufficed, but as in the future new plants will be added heavier line conductors were employed.

There is a total of 2260 towers, which were erected by two gangs, each consisting of 40 men capable of erecting, on the average, 20 towers per day. As nearly the whole course follows the river Isar, all of the material was conveniently transported on boats.

There are only a few special structures throughout the whole line. Wherever the transmission line crosses a telephone line higher poles are chosen. No guard or net wiring is employed. In one instance a special lattice girder construction was erected for crossing the State telephone system. The line crosses the Isar three times, and at these points special angle-iron lattice-constructed towers are made use of to carry spans of 365 feet. For these spans, instead of copper, bronze conductors of 29 sq. mm. were used. The poles are grounded by a 12-inch by 12-inch plate; all poles are interconnected electrically by an iron wire.

The whole line is transposed three times, thus dividing the line into four sections, to nullify the electrostatic and inductive effect on the telephone line. The last transposition brings the phase leads into their original position.

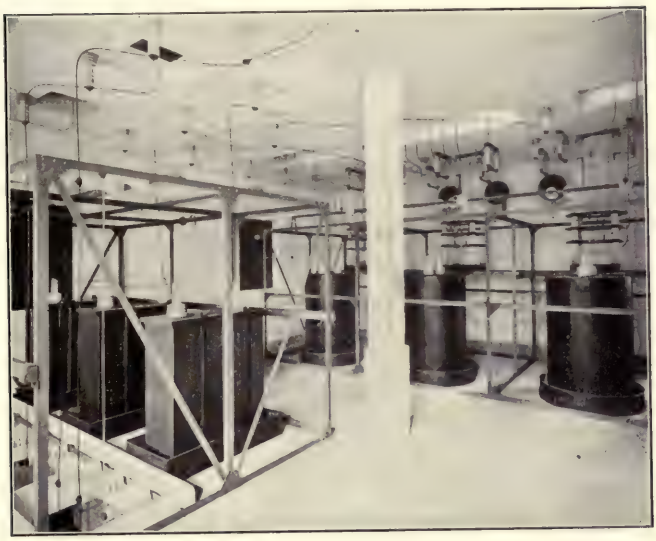


FIG. 8.—Lightning Arrester Equipment at Substation Hirschau, Uppenborn System, Germany.

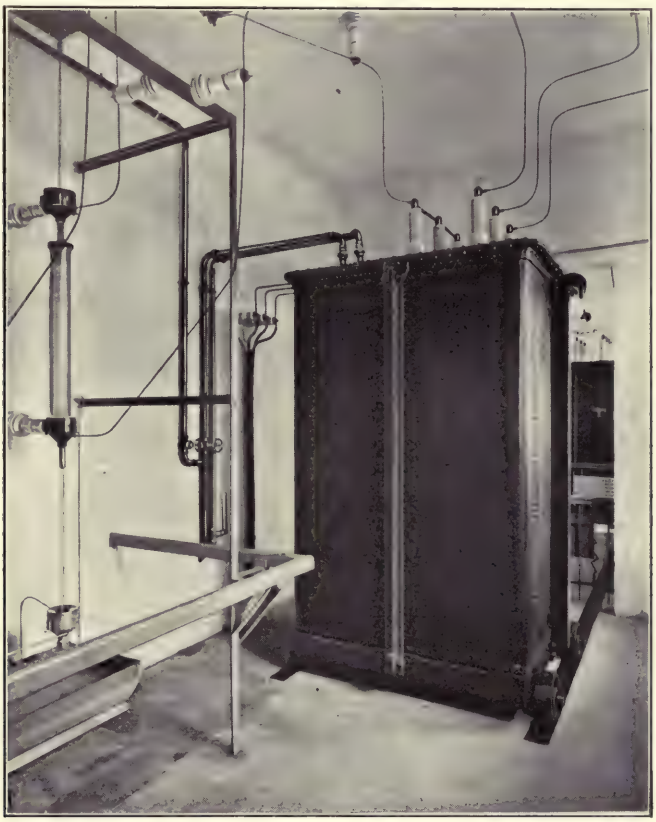


FIG. 9.—Transformer and Water Flow Grounder, Substation Hirschau, Uppenborn Transmission System, Germany.

Section House. Midway between the power house and Munich, at Achering, there is a lightning-arrester station, through which the circuits pass. This station is divided up into two separate rooms, one for each circuit. Here are located three horn-gaps with 2-inch setting; they are 6 feet apart, separated by double asbestos partitions. Each phase lead is connected to a 5000-ohm rheostat submerged in oil and then grounded by plates connected to the ground wires of the towers. Section switches are placed between the lines and horn-gaps, so that the latter can readily

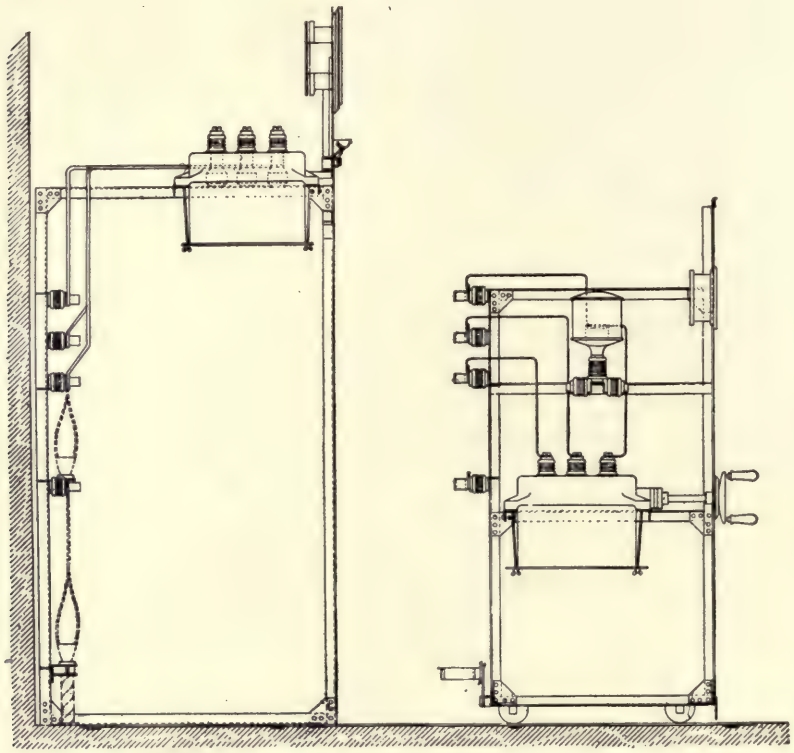


FIG. 10.—Siemens-Schuckert Wagon Panel.

be cut out. Line section-switches are placed at intervals of 0.6 mile in order to facilitate the localization of faults.

The four sections are watched by four patrolmen, each covering twice daily eight miles. After a quarter year of operation it was found more economical to replace the four patrolmen by two men mounted on motor-cycles.

The lightning-arrester station has two telephones, one for each transmission line. They are carried on the towers of the transmission line about 3.5 feet below the lowest conductor. The telephone lines are transposed every 650 feet to counterbalance any inductive effects.

Substation. Energy is received at the end of the line at the Hirschau transformer station at about 48,000 volts, the E.M.F. being then transformed to 5000. The lines enter the substation with protection devices similar to those at the power house, and feed into the two three-phase transformers. On the secondary side is a 5000-volt bus-bar system, divided into two sections by sectionalizing switches. From here three connections are made to the already existing distributing system in the city of Munich.

The transformer station is seen in Fig. 6. The adjacent small building contains protecting apparatus for direct lightning strokes. The architecture of the buildings,

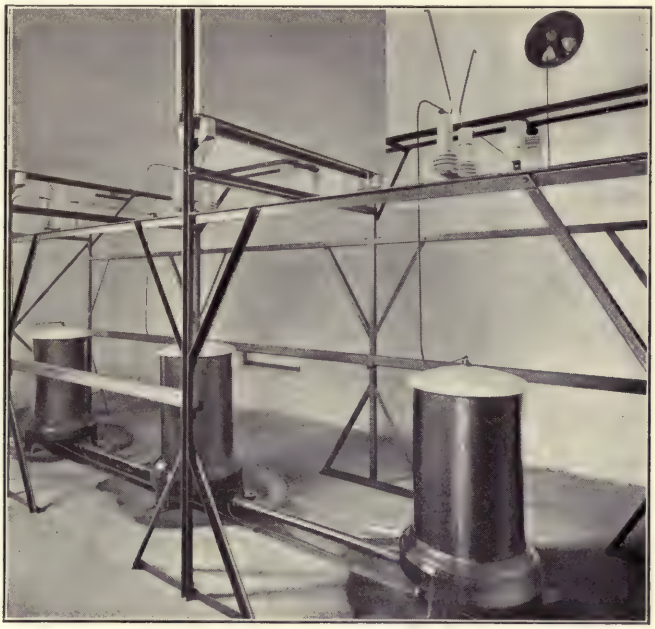


FIG. 11.—Horn Gaps and Water Rheostats in Lightning Arrester House at Substation, Hirschau, Germany.

particularly that of the larger one, is that of a south Bavarian farmhouse. It is built up of brick, to which stucco is applied. On the ground floor it contains the transformers, 5000-volt switching apparatus and water flow grounders. On the second floor are the generator choke coils, placed in oil; choke coils and oil rheostats. On the upper floor, directly above the choke coils, are the horn-gap arresters.

The transformers are of the Siemens-Schuckert type, similar to those installed in the power house. Each is located in a room separated by an inspection or repair room. They rest on rollers and tracks and can readily be moved.

The switchboard in the substation is also of the wagon panel type of Siemens-Schuckert make, and differs from the previously described one in that the wagon is a

whole panel running on tracks in the floor of the switching room. Each wagon contains an oil switch operated by hand, provided with an overload relay and one ammeter with its transformer.

There is a 7-K.W., 5000/110-volt, three-phase transformer to supply energy for the operation of two centrifugal pumps, for circulating the cooling water of the transformers, and for water-flow grounders, rheostats, etc. This transformer also supplies energy to a 1-K.W. motor generator set, assisted by a 30-volt battery of 81 ampere-hour rating, to light the station.

Telephones. The transformer station is connected to all stations and substations with which it runs in parallel by private and local telephones and with the main generating station in three different ways. Two are the high-tension lines running beneath the 50,000-volt circuits, and the other runs along the poles of the long-distance state telephone, which is not influenced by high-tension lines.

Special precaution is taken with the high-tension telephones to guard against all possible danger. As stated, the 50,000-volt transmission lines are transposed twice, and the telephone line every 650 feet. This arrangement, however, was not considered perfect. The telephone line is carried on two-piece, three-petticoat insulators tested at 70,000 volts. The telephone is protected first by small horn-gap arresters, then high-pressure fuses grounded with small spark gaps; next by fine fuses known as "Bosepatronen," grounded by two carbon telephone lightning arresters. A variable water rheostat is shunted in ahead of the Bosepatronen, and by adjusting the electrodes the buzzing effect of electrostatic induction is eliminated, thus giving good articulation.

It was thought unsafe to connect the line directly to the transmitter, therefore between the latter and the line is cut in a microphone-telephone, which is connected to the transmitter by pressed paper tubes. The receivers are connected to the telephone by flexible tubes.

Cost. The table below expressed in marks gives comparative figures of the entire system, which totalizes approximately $800,000.

Items	Marks.
1. Main dam	855,523.06
2. Regulating gates	138,124.64
3. Headrace and turbine substructure	1,065,129.04
4. Station superstructure	86,522.42
5. Turbines and gates	142,393.95
6. Electrical equipment	272,046.57
7. Transmission system	464,552.02
8. Transformer stations	134,590.38
9. Accessories	42,216.59
10. Retention dams, fish rights, etc.	62,939.65
11. Supervising charge	26,320.23
Total	3,290,358.55

THE BRUSIO HYDROELECTRIC PLANT AND ITS 50,000-VOLT SWISS-ITALIAN TRANSMISSION SYSTEM.[1]

The largest and most recent hydroelectric installation in continental Europe is that at Brusio in Campocologna (Granbünden), the southeastern corner of Switzerland. Some 3155 feet above sea level, bordered by the slopes of the Bernian Mountains, lies the lake of Poschiavo. This lake receives, among others, the waters of the River Poschiavino and its tributaries as well as those of the River Cavagliasco, which in turn collects the waters of the glaciers Cambrena and Palü. The total drainage area which feeds this lake is 75 square miles. The area of the lake is 0.77 square mile, and the greatest depth is 260 feet.

Owing to the high altitude of the lake, the water supply in the winter time is considerably less than during other seasons, consequently the equipment of the plant with proper regulating devices became very essential. Therefore one of the foremost requirements consisted in damming the lake at its outlet, where the River Poschiavino continues, so that the water level of the lake may be raised 3.3 feet above the normal, and lowered by siphoning, as much as 24.3 feet below the normal level, thus providing a natural reservoir, giving a reserve water supply of 520,000,000 cubic feet.

The headrace leading from the lake is carried to Monte Scala, a distance of 3.25 miles, where a collecting basin is provided by a tunnel through the mountain at a considerable depth.

The power plant is located at Campocologna, receiving the water through penstocks from the collecting basin under a head of 1300 feet. Current is generated at 7000 volts and transmitted through a tunnel across the boundary into Italy, where, at a substation in Pittamala, the voltage is stepped up to 50,000 for use by the Societa Lombarda, an Italian distributing company, to work in parallel with their well-known stations in Vizzola and Castellanza. This company guarantees the use of 16,000 K.W. From the power plant itself several aerial lines transmit current to various other consumers in Switzerland, and among them it will assist a small power plant, still under construction at Saiento.

The 50,000-volt transmission line, from Pittamala to the substation at Lomazzo, is 88.5 miles in length and consists of two independent lines. A 20,000-volt transmission line branches off northward to Como from the station at Lomazzo, running a distance of 30 miles. An 11,000-volt line runs southward 8.5 miles to the steam-power plant at Castellanza for assisting or drawing current from same. The bulk of the current is used in spinning and weaving mills, which begin operations at 7 A.M.; reaching the maximum in a half hour, the load remains steady up to 12 o'clock noon, dropping in thirty minutes to a few hundred kilowatts and again reaching the maximum at 1 P.M., where it remains up to 7 P.M. During the night only 2000 K.W. are necessary.

The entire hydroelectric development and transmission system is considered the

[1] Author's article, *Electrical Review*, Aug. 8 and 15, 1908. Based on data submitted by the Designing and Constructing Engineers.



FIG. 1.—Power Plant at Brusio, Switzerland. Showing Penstocks, Generating House and Cable Tunnel, Tailrace Water Discharge below the Cable Tunnel.

most up-to-date in Europe, embodying many excellent examples of modern European practice.

Siphon System. As the level of the water in the lake will vary in the neighborhood of 30 feet, the headrace tunnel is located 32.8 feet below the normal water level. It was not advisable to connect the tunnel directly with the bed of the lake, therefore a siphon was installed. For this purpose a shaft was sunk about 75 feet from the water's edge and carried 7.4 feet below the low-water level. The shaft is 12 feet in diameter, and the portion below water level was built under air pressure. From this shaft, the headrace or supply tunnel, having a diameter of 8.9 feet at this point, leads to the collecting basin.

The lake is connected to this shaft by means of a siphon tube 6.5 feet in diameter and 270 feet horizontal length or body. The suction leg is 26 feet long, provided with a screen and butterfly valve, while the discharge leg is 27.7 feet long. The latter is provided at its bottom end with a disk valve for regulating the flow of water. The tube has a pitch of 5 feet in 1000, and is provided at its highest point with nozzles; one being 35 inches in diameter, connected to a double-stage air-pump for starting the siphon, and the other, an 8-inch connection for a centrifugal pump, which is used for cleaning the siphon tube, and particularly the screen. Instead of using the air-pump for starting, the centrifugal pump may be called upon, in which case both butterfly and disk valve are first closed. Since about 180 feet of the horizontal length of the siphon is located in the lake under the normal level, this portion of the tube, made in sections of 36 feet, was fitted at its ends with blank flanges, and then floated to its position between piles and anchored to the framework of the piling. The final flange connections were made by divers.

Secondary Water Supply. For the purpose of damming the water in the lake, six sluice gates were built at the outlet, five of these being 13.12 feet wide, and one being 6.56 feet wide. The smaller one, which is located lower than the others, is used for passing sand and gravel. Located at right angles to the dam or sluice gates, is a small basin provided with a screen. A 33-inch pipe, provided with a gate, leads from this basin to the headrace tunnel, 800 feet below, where a shaft was sunk to receive the pipe; this arrangement, constituting a second water supply, was utilized in order to start the plant at an early date. The size of this pipe was so chosen, that it might later be used as one of the penstocks leading from the collecting basin to the power house. This pipe by-passed the upper section of the headrace tunnel and the siphon system, and furnished the water supply during construction pending the securing of necessary concessions.

Headrace. The headrace is 17,056 feet long, 4920 feet running through moraine (a formation similar to landslides), and the remainder through gneiss. A portion of the tunnel, near the collecting basin, lies about 100 feet deep, while the greatest portion of its length lies some 425 feet beneath the surface. With that portion of the tunnel lying at the greatest depth, and running through the gneiss formation, no difficulty was experienced from seepage or air leakage, while in the portion nearest the surface, and where the tunnel runs through moraine, such difficulty was experienced. For the purpose of draining the seepage water and discharging the air,

11 lateral tunnels were cut, having their outlet at the nearest point on the mountain slope.

The tunnel, where cut through the rock, was lined with concrete to a point above the water-line, while a portion of the tunnel above the water was left unlined. Where the tunnel runs through the loose earth (moraine), it is constructed partly of concrete and partly of reinforced concrete; and where it was cut through the rock, pneumatic drills running on tracks were employed. For this purpose, and for lighting, a temporary power plant was installed, utilizing the fall of the Sajento River. The headrace was constructed of a wooden flume 910 feet long and a 12-inch steel penstock. A 50-H.P. turbo-generator, giving 4000 volts, was installed; the turbine also operated a two-step compressor supplying air at 90 pounds pressure through two main pipe lines.

At three of the seepage-discharge tunnels, ventilators were installed during construction, while at the remainder, ventilation was produced by means of branches from the compressed-air lines. Leading to the mouths of the seepage-discharge tunnels, Nos. 6 and 9, 1000 to 1500 feet above the valley, were electrical cable transportation lines.

At seepage-discharge tunnel No. 2, near the lake, an overflow system is provided with a sand and gravel trap.

The entire tunnel, which is egg-shaped with a flat bottom, has a slope of 2 feet in 1000, and has a sectional area of 53.5 square feet. The average velocity of the water in the tunnel, when partly filled, is 6.5 feet per second. Should the possibility arise that in the future the tunnel should be used as a pressure tunnel, for which provision has been made, the velocity of the water will be 5 feet per second.

As will be noticed from the dimensions of the tunnel given above, the volume of water contained in same furnishes auxiliary storage capacity to the collecting basin. Furthermore, for a length of one mile, the sectional area of the tunnel was increased, and in order to properly regulate the water supply to the collecting basin, an additional overflow was provided at seepage-discharge tunnel No. 9, discharging into the above-mentioned Sajento River. The collecting basin is so dimensioned, that with average loads, the level of the water will be constant; while with light loads, the level of the water will be higher; and during the hours of maximum load, the water level will be correspondingly lower.

Collecting Basin and Penstocks. The collecting basin is located 1300 feet above the valley, and is provided with six penstock connections arranged in pairs in separate chambers provided with screens.

The usual practice of providing the penstocks with cut-off gates has not been followed, owing to the sudden rise and fall of the water. An automatic float arrangement for signaling the attendant was installed, operating by releasing a pawl and a magnet clutch, and allowing a flap gate to close.

About 100 feet from the collecting basin is a gate through which pass the six penstocks. At the headgates, they have a diameter of 33.5 inches, and owing to the high head (1380 feet), considerable material was saved by reducing the diameter at the power house to 29.5 inches, by telescoping certain sections of the penstocks, thus

A.E.&M.E
UNIV. OF CAL

giving at its lower end, a water velocity of 11.5 feet per second. The penstocks are made up of rolled steel, in sections 39.36 feet in length. The heaviest material employed is seven-eighths inch. The sections are bolted together by the use of movable flanges. As will be seen in Fig. 1, the penstocks run down the mountain slope at various angles, and are anchored in solid concrete blocks, there being ten anchorages. Between these anchorages the penstocks rest on concrete piers, the expansion being provided for by the use of slip expansion joints. At the headgates (Fig. 2), each penstock is provided with a vent pipe about 45 feet high.



FIG. 2.—Gate House for Penstocks, Brusio Plant, Switzerland.

Drainage gates are provided at the lower ends of the penstocks, for draining into the tailrace. Here the six penstocks are interconnected by a cross pipe having two outlets, one leading to the exciters, and the other being provided with a safety device so that in case of excess pressure, the " bursting plate " gives way and relieves the penstocks. This cross-pipe connection also serves the purpose of maintaining a uniform circulation. There are at present installed, corresponding to the main turbo-units, five penstocks. For hoisting the penstocks and other materials during construction, an electrically operated cable road was installed. The drum and motor are located in an annex to the gate-house near the collecting basin.

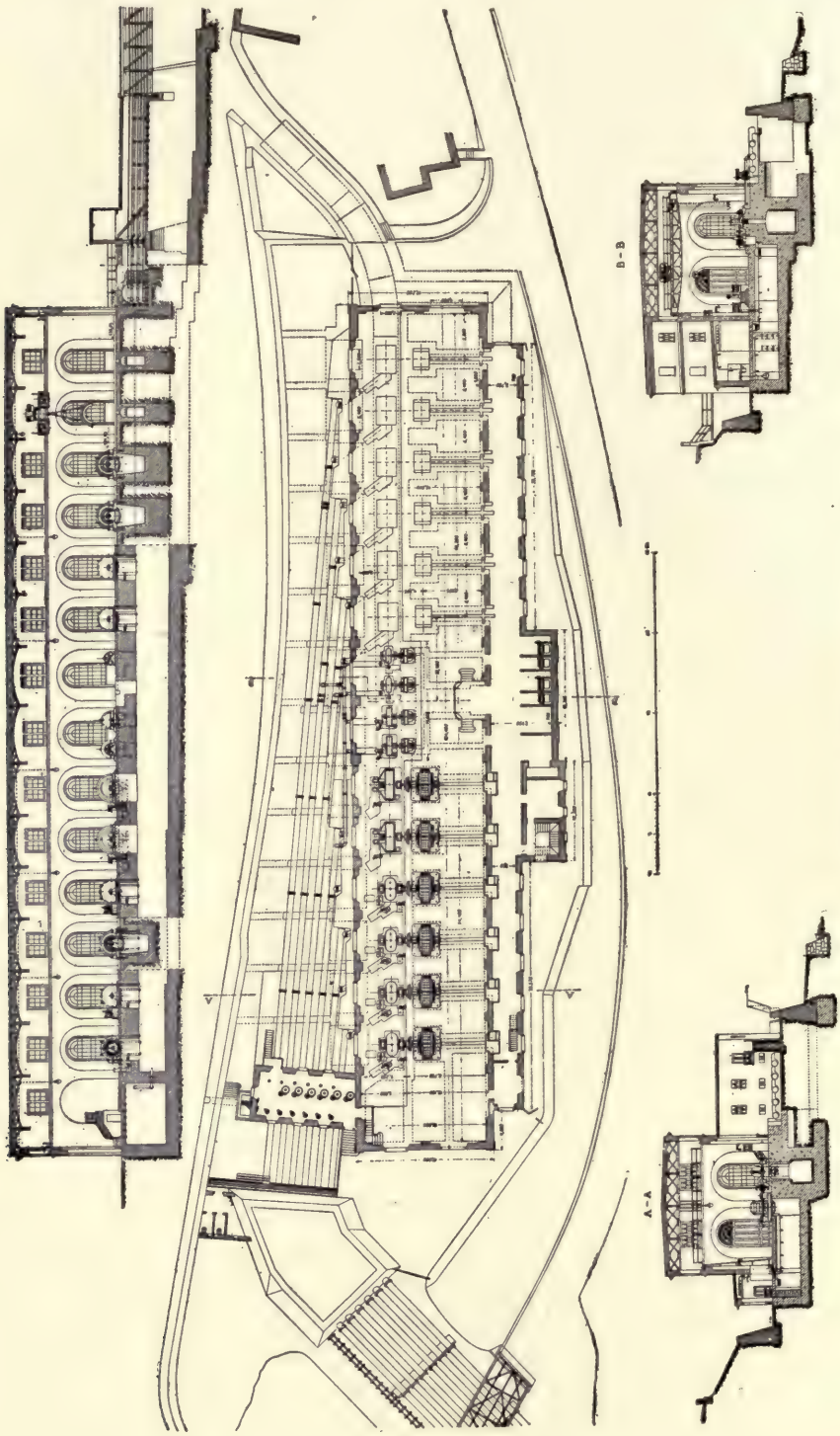


FIG. 3.—General Layout of Power Plant, Brusio, Switzerland.

Power House. The power house is located at Campocologna alongside the river Poschiavino. The main generator room is 342 feet long by 56.4 feet wide. At the side, there is a single story switch annex 311.5 feet long by 10.75 feet wide, with a three-story central section for offices.

Owing to the typography, heavy retaining walls were required, with deep and expensive building foundations. Up to the main generating room floor, the building is of concrete, while the superstructure is of quarried stone and tile. The roof construction is expensive and is as follows: Between I-beam purlins, are large tile blocks the undersides of which are glazed, to form a finished ceiling. These are covered with a one-eighth-inch layer of cement over which are spread three layers of so-called wood-cement (sawdust and cement), between each of which is laid a layer of paper. Above the layers of wood cement are reinforced concrete slabs, an air space of two and three-eighths inches being left between these slabs and the wood cement. These precautions have been taken on account of the extreme heat in the summer time.

The building accommodates 12 main units, each of 3000 to 3500 K.W. capacity, and 4 exciter units of 250 HP. each. Ten of the main units are at present installed. A 25-ton electrically operated crane serves the entire generating room.

Turbo-Generator Units. There are two different types of turbines installed — the impulse wheel of Escher Wyss & Co., of which there are at present ten installed, eight main and two exciter turbines; and the Girard turbine with partial admission, of Picard, Pictet & Co., of which there are at present installed two main and two exciter turbines. The main turbines (3000 K.W.) run at a speed of 375 R.P.M. and the exciters (150 K.W.) at 430 R.P.M., and operate under a head of 1300 feet. The turbines are direct-connected to the water wheels by flexible insulated couplings of the Zodel-Voith type.

The generators are 3000-K.W., three-phase, 50-cycle, 7000-volt machines, and are designed for an overload capacity of 25 per cent. They are of the 16-pole, revolving field type. The poles are cast directly to the field ring. The stator is made in halves, and has a bore of 10 feet 2 inches, the width being 3 feet 7 inches. The bed plate is made in two sections, with the bearings cast on.

The Elektrizitäts Gesellschaft Alioth, Münchenstein-Basel, Switzerland, manufacturers of the generators, who installed also the entire electrical equipment, guarantee the efficiencies as follows:

Load.	Power factor, Cos ϕ = 1.	Cos ϕ = 0.7.
Per cent.	Per cent.	Per cent.
0.25	93.5	92.0
0.75	95.0	93.5
1.00	96.0	94.5
1.25	96.5	95.0

The four exciters are of the 6-pole, 115-volt, shunt-wound type. They develop 150 K.W. at 450 R.P.M. Each exciter serves four generators, with twenty-five per cent overload.

Switchgear. Contrary to the usual practice of centralizing the switchgear, because it was thought best for the convenience of operation and a material decrease in first cost and simplification of the wiring system, each generator has its own switchboard. As will be seen in Fig. 4, these switchboards are located against the wall next to the switchroom, and directly opposite each generator.

Thus the station is divided into complete unit systems. However, to control all switchboards from one central point an instrument column has been installed.

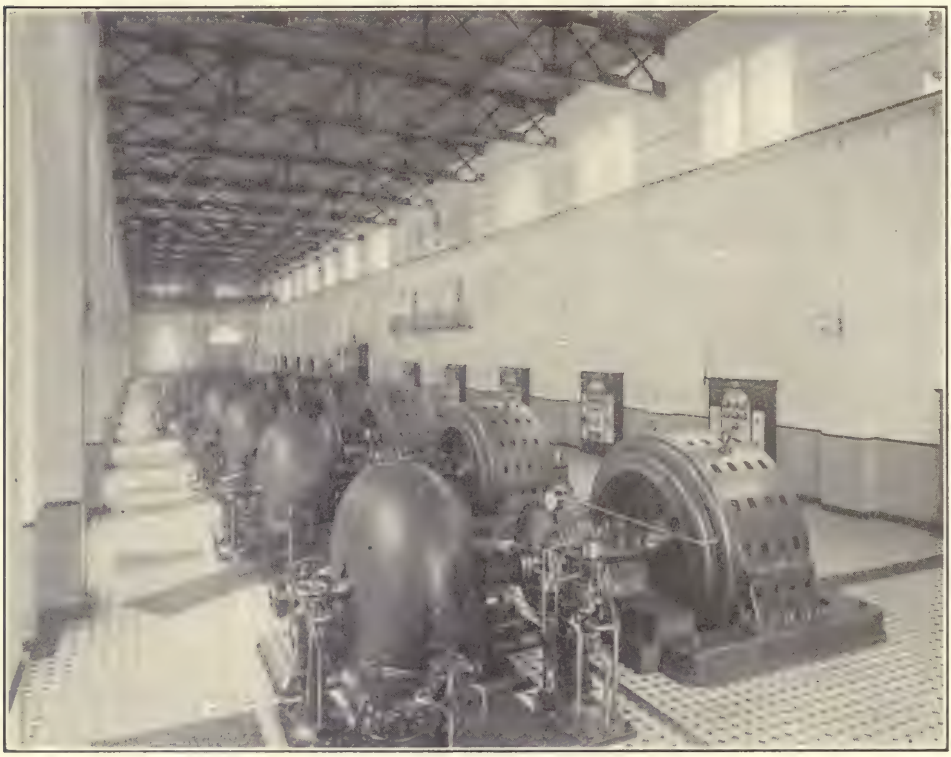


FIG. 4.—Interior of Brusio Power Plant.

The switchboards are of ornamental design and faced with white marble slabs. All high tension parts of the switchgear are located on the opposite side of the wall in masonry compartments fitted with corrugated iron rolling shutters. Each generator switchboard is equipped with the following instruments: two voltmeters; one synchroscope; with phase lamps; three ammeters, one for each phase; one three-pole oil-switch, which may be operated by hand or automatically. There are, further, an ammeter on the central column, a main current rheostat for excitation, and a field discharge resistance.

Owing to the non-centralization of the switchgear system, it was not considered necessary to install a double bus-bar or ring system, so common in Swiss practice. There is one main and one exciter bus; both systems are divided in the middle by

sectionalizing switches. The arrangement is such that a group of three generators may also be independently excited and thrown upon separate bus-bars. The current from these three generators is intended for the valley of Brusio and for the operation of the Bernian Railway.



FIG. 5.—Individual Generator Switchboard.

The outgoing feeders, with the exception of those just mentioned, are connected at the middle of the bus-bars, which are made up of copper strips, two by three-sixteenths inch being sufficient for one generator. Thus, where each generator connection joins the bus-bar an additional layer has been added. The bus-bars run the entire length of the switchroom, above the aisle and close to the ceiling. They are carried on petticoat insulators fastened to I-beams, and are securely

anchored in the middle and at the ends, so that in case of a severe short circuit the different phases will not be thrown together.

The exciter switchboard (Fig. 8) is located upon a platform in the middle of the generating room, opposite the exciters. It is provided with four white marble panels, one for each exciter, and upon each are mounted a voltmeter, ammeter, knife-switch, shunt rheostat, and a reverse current circuit-breaker.

In front of the exciter switchboard is the above mentioned central instrument column, upon which are mounted the following instruments: an ammeter, with multiple throw switch, to read the current of each generator; one voltmeter, with plugs, for each phase; two ammeters, one for each of the outgoing feeder systems of the Societa Lombarda, and one hand wheel, operating a shaft to which are connected the shunt rheostats of the four exciters. From this column one attendant may control the operation of the entire plant.

Current Supply. As previously stated, much of the current generated is transmitted across the boundary line into Italy, and it was deemed advisable to run duplicate circuits to the substation at Piattamala. Since, however, the valley is quite narrow and atmospheric discharges are of great frequency, a tunnel was built for the purpose of carrying these wires to the station.

The conductors leave the basement of the switchroom and cross the River Poschiavino through a covered bridge (Fig. 1), where they then enter the tunnel mentioned. This tunnel, which runs to a substation, is 1650 feet long. It is 8.2 feet wide and 9.8 feet high, the top being arched.

Owing to the customs regulations between the two countries, the tunnel cannot be entered from the power house end. Entrance is obtained, however, through a door visible from the street; at the boundary line, the tunnel is closed off by an iron door separating the Italian and Swiss sections.

The accompanying cross section, Fig. 9, illustrates the scheme of arranging the conductors in the tunnel. They consist of copper bars 0.25 square inch in section, which are carried on petticoat insulators supported on channel irons projecting from the side walls of the tunnel. These channels are spaced longitudinally for 4.9 feet, with reinforced concrete slabs spanning them, forming partitions between the conductors. The outgoing 7000-volt feeders tap the middle of the bus-bar system, then are carried on either side of the tunnel to the substation. For the protection of the customs officials, the circuits are fenced off by removable wire netting.

Step-up Station, Piattamala. This station is built in the shape of a T, 180.5 feet long, 68.8 feet wide, and 28.2 feet high, the cross wing being 92 feet long and 42.6 feet high. It is designed to accommodate 24 single phase transformers having a capacity of 1250 K.W. each. At present there are thirteen installed, with a total normal capacity of 16,250 K.W.

At one end of the transformer room is the meter room, where the current is checked by the two companies. The transformers are arranged in two rows, between which are two tracks leading into the inspection and repair room. This is in the middle of the cross arm of the T, in which there is a 10-ton traveling crane. The

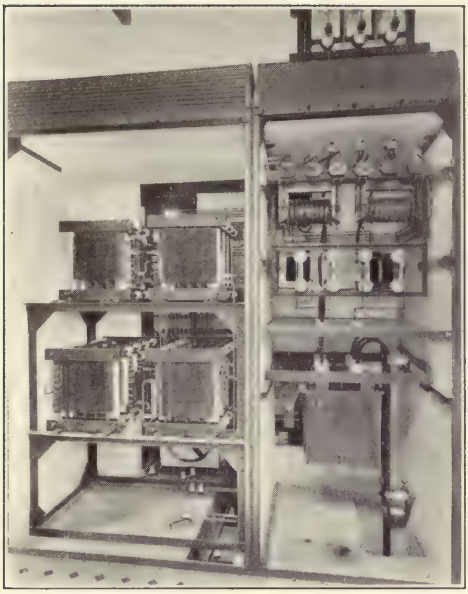


FIG. 6. — Back of Individual Generator Switchboard, Brusio Plant, Switzerland.



FIG. 7. — Rear of Switchboards, and Generator Busses.

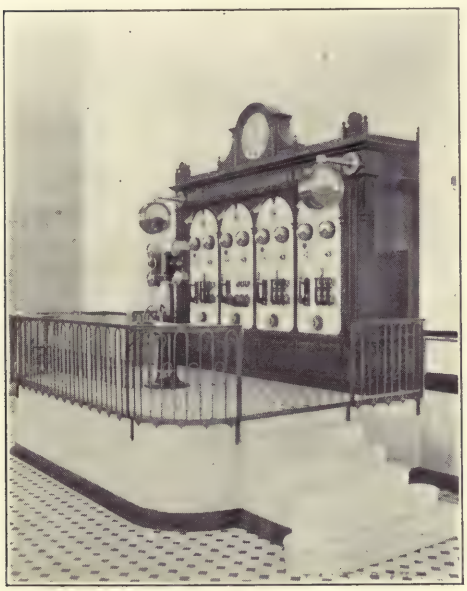


FIG. 8.—Exciter Switchboard and Control Pedestal.

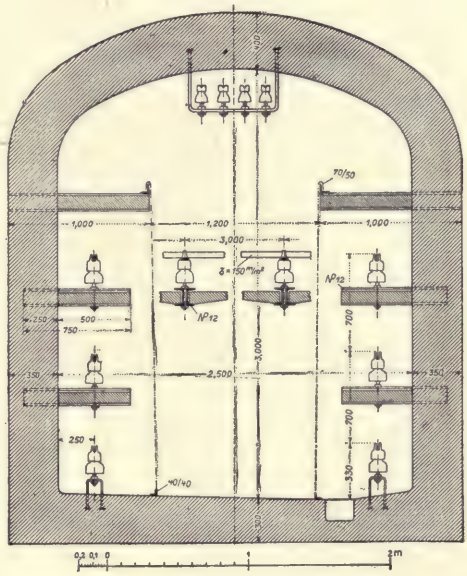


FIG. 9.—Cross Section of Cable Tunnel leading across Boundary, between Power House, Brusio, Switzerland, and Step-up Station, Piattamala, Italy.

transformer switchboard rooms are directly behind each row of transformers. The substation is divided into two distinct sections. The outgoing feeders leave the building from the third story of the cross wing.

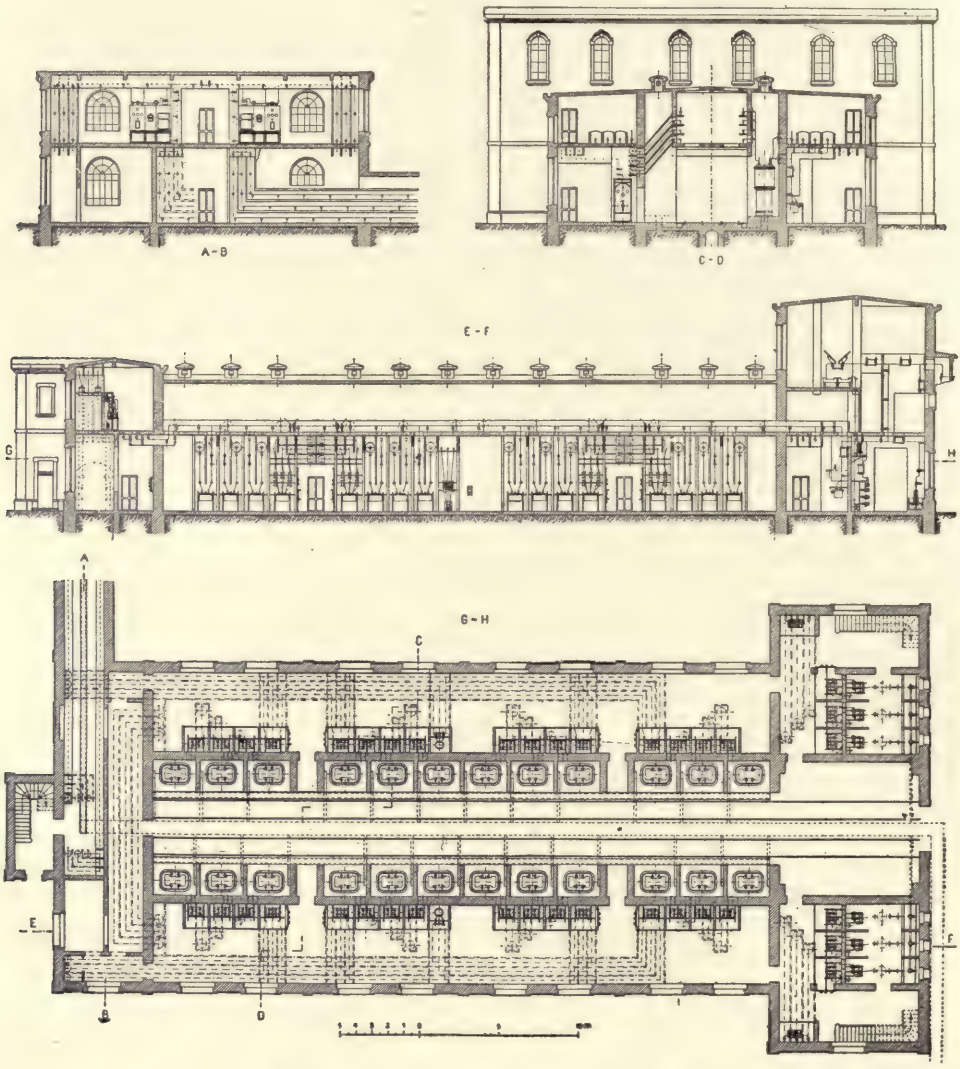


FIG. 10.—Step-up Transformer Station, Piattamala, Italy.

The feeder lines from the power station enter the substation from the tunnel on the ground floor, as the station is built into the hillside. As two companies are concerned in the amount of current used, the Brusio Company supplying and the Societa Lombarda receiving the current for distribution, this room, on the ground floor, is thoroughly equipped with measuring instruments, some of which are kilowatt meters of different makes, and are switched in series in order to check each other.

The switches are so arranged that the current may be thrown onto either row of transformers, from either of the two feeder lines, or the current from both feeders may be thrown on one row of transformers only. The oil switches, in the meter room, are of the remote-control, hand-operated type. It was not deemed advisable to install automatic switches, because a sudden cutting out the whole load, which might amount to 20,000 K.W., might seriously interfere with the operation of the plant, particularly the hydraulic end.

Above the aisle, between the two rows of transformers, and extending the full length of the room, is a mezzanine floor carrying the feeders in two vertical rows,



FIG. 11.—Switch Room and Step-up Transformer Station, Piattamala, Italy.

one on either side of the transformers. The phases of the bus-bar system are separated by concrete shelves, the front remaining open. The high-tension, or 50,000-volt bus-bars run on the mezzanine floor above the transformer switchboard or operating rooms. These bus-bars are arranged in horizontal rows separated by concrete partitions, but not covered.

The transformers are of the Alioth water-cooled oil type, a system of water circulation from a spring, under a head of 26 feet, being provided. The efficiency of the transformers under actual test at full load was 97.5 per cent; at half load, 96.5 per cent. The drop in voltage between no load and full load, with a power factor

$\cos \phi = 1$, is one per cent. With $\cos \phi = 0.8$, is 2.2 per cent. The greatest drop is 2.8 per cent.

Each transformer is contained in a well ventilated concrete compartment, the front being provided with a corrugated iron rolling shutter. The transformers are provided with pinion wheels, resting on pairs of racks, secured to the floor, the transfer table also being provided with such racks. This device greatly facilitates the handling of the transformers, a ratchet being used for moving them onto the transfer table, by which they are transported on the track to the inspection and repair room, where the cores are easily taken out by the overhead crane.

Each transformer is provided on the low-tension (7000 volts) side, with a three-pole oil switch, while on the high-tension side (50,000 volts), three oil switches, one for each phase, are provided. These switches, interconnected, are remote controlled, and may be operated either by hand or automatically. Access to the 7000-volt switches, which are protected by doors, can only be had when the current is off. The 50,000-volt switches are similarly protected. All these switches are accessible from the aisles of the operating rooms. Between each group of transformers, sectionalizing switches and choke coils are provided for protection against variations in load caused by throwing the switches.

Protecting Devices. On account of the high tension and long transmission line, the great variation in altitude and consequent difference in temperatures, and particularly on account of the frequent storms and atmospheric discharges, various devices were installed for protection against surges. For this purpose, the choke coils above mentioned are placed on each side of the transformers, and horn lightning arresters are placed on the outgoing feeders. The latter have a gap of two and three-eighths inches and are connected in series with waterflow resistances. The choke coils consist of two spools, having a brass core, upon which is tightly wound a copper band of sixty turns, separated by insulating material, forming a solid, tightly wound spool, which sudden surges will not distort.

For taking up lighter static and atmospheric discharges, the more sensitive role lightning arresters were installed and connected in series with waterflow resistances. Finally, as all surges will create more or less variation in pressure, waterflow grounders are installed for each phase, to maintain a uniform pressure. This apparatus consists of a nozzle for forcing a jet of water, under a head of 26 feet (supplied from above-mentioned spring), against a baffle plate connected to the line. The stream of water is three-eighths inch diameter and 28 inches high, and allows a leakage of one-tenth ampere. Ammeters are inserted in the wire connection to this apparatus, in order to detect failures in the grounding.

All lightning arresters, as well as the outgoing lines, are provided with disconnecting switches. All metallic features of the installation are interconnected and well grounded.

Transmission Lines. The transmission line (50,000 volts) may be considered the most important in Europe. It consists of two independent lines, each 88.5 miles long. As the line runs over mountains and valleys, peaks were avoided as much as possible, to escape the unavoidable difficulties due to atmospheric discharges. These

lines cross three provinces and 94 townships, and required the right of way through 6000 properties, the cost of which averaged about $800 per mile. The lines cross ten railways, one tramway, ten state roads and 120 county roads.

From the main substation at Piattamala, the line runs westward through the Adda Valley to Colico, thence along the shore of Lake Como to Bellano, from which point it runs in a southeasterly direction over the Valsasina Plateau. Palasco, the highest point of the line, is 2130 feet above sea level. From Valsasina the line runs in the mountains of Lecco in a southwesterly direction, and cross the Adda Valley with a span of 720 feet, this being the lowest point of the line (640 feet above sea level). From here, until the first step-down station, at Lomazzo, is reached, 88.5 miles distant from the step-up station at Piattamala, the run is practically straight. Eight and one-half miles beyond Lomazzo, at Castellanza, is another step-down station.



FIG. 12.—Brusio 50,000-volt Line, Crossing Railway.

The average span is 393 feet. In 87 cases, however, the span exceeded the average, the longest span being 1280 feet, across the Gravina Valley at Colico. The transmission line consists of two parallel rows of towers, from 13 to 16.5 feet apart, of latticed-girder construction embedded in concrete. Each tower is provided with six brackets, three for present use and three for future extension, so that there will be eventually four separate three-phase circuits. The porcelain insulators are supported on pins, fastened to oak and chestnut blocks secured to steel brackets. Each cable consists of nineteen wires, 2.6 mm. in diameter, the total diameter of the cable being 14 mm. (105 square mm. area).

The towers are calculated for a wind pressure of 70 miles per hour, allowing a stress in the copper of 8500 pounds per square inch, and on the tower of 17,000 pounds per square inch.

Allowance is made for a temperature difference of 120° F. On account of the difference in the spans and frequent changes in direction of the lines, four different types of towers are employed, weighing from 1250 to 2500 pounds each. There is a total of 3100 towers, averaging in price $80 each, including foundation and erection. The two existing lines represent 900 gross tons of copper and 10,000 insulators at $2.60 each, including mounting and wooden blocks. The laying of the cables cost $128 per mile of transmission.

The transmission system is divided into six sections, varying from 8.5 to 25.5 miles, and is provided with section switches so arranged that in case of a break in a section of one line the current may be by-passed over the other. There is a small station at each section, for housing the sectionalizing switches, measuring apparatus, lightning arresters, some of which are of the horn type, some of the coil type, and some are also provided with water-flow grounders as described previously.

At a distance of 65 feet, and parallel with the high tension lines, a telephone and telegraph line is carried the entire length of the transmission system, for the exclusive use of the plant. There are two wires carried on wooden poles; and 30 stations costing $30 each, while the line costs about $380 per mile.

Transformer Station, Lomazzo. This substation is located centrally in the low tension distributing district. It is built in the form of an I. The wing at one end, containing the apparatus for the incoming feeders, is 85 by 30 feet, and 48 feet high. The wing at the opposite end is of the same dimensions, and contains the apparatus for the outgoing feeders. The middle member of the building, containing the transformers, is 55 feet wide, 60 feet long, and 33 feet high. The over-all dimensions are 85 by 120 feet.

The two 50,000-volt circuits enter the second floor of one of the wings in a way similar to the outgoing feeders leaving the step-up station at Piattamala. They are similarly protected against electrical discharges, except that the water-flow lightning arresters are supplied with water by a centrifugal pump and tank under a head of 40 feet instead of a natural head from the mountain stream. The transformers (1250 K.W. 50,000–11,000 volts) are arranged in two rows, similar to those at Piattamala, with tracks in front of the compartments, of which there are six on each side. There are also six three-phase transformers of 5000 K.W. each (11,000–20,000 volts). There are at present installed only three single-phase and three three-phase transformers. While the transformers at Piattamala are of the oil-cooled, water-circulating type, those at this station (Lomazzo) are of the forced air-cooled type, for which two blowers are at present installed. The final equipment demands four blowers, of which two will be kept in reserve. The blowers are motor-driven and discharge through air ducts located beneath the two rows of transformers. The cores of the transformers are not encased.

The fronts of the transformer compartments are provided with rolling shutters; ventilators are placed in the roof. Good results were obtained with these trans-

formers, an advantage being that the cores can be easily inspected. The primary winding is provided with taps, so that the voltage may be reduced to 35,000. This was done so that easy regulation might be secured. The tests show that the efficiency at full load is 97 per cent, and at half load 96.5 per cent. The pressure loss at full load with power factor of $\cos \phi = 1$ is one per cent, and with a power factor 0.8 it is 3 per cent. The temperature rise is 40° C. The high and low tension sides, respectively, were tested to 65,000 and 17,000 volts, 10 minutes duration. The transformers are capable of standing an overload of 25 per cent with a total temperature

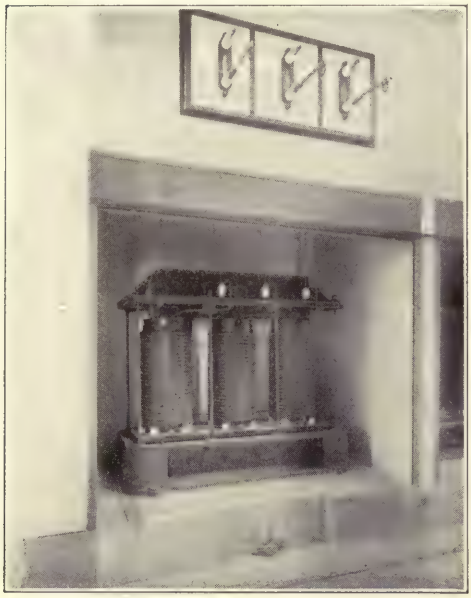


FIG. 13.—5000-K.V.A. Open Type Air-Cooled Transformer at Lomazzo, Italy.



FIG. 14—50,000-volt. Switch Room at Substation, Lomazzo, Italy.

rise of 60° C. The operation of the blowers is included in the aboved-named efficiencies.

The 11,000–20,000 volt, 500 K.W., three-phase transformers have an efficiency of 97 per cent at full load with a power factor of $\cos \phi = 1$, while with $\cos \phi = 0.8$ it is 96 per cent, and three-quarters load 96 per cent and 95 per cent, while at half load it is 95.5 and 94.5 per cent. The drop in pressure is 1.5 per cent with a power factor of $\cos \phi = 1$, and 3 per cent with a power factor of 0.8. The temperature rise is 50° C., and the overload capacity is 20 per cent for two hours.

Distribution. The wiring diagram is made so that under normal operating conditions the line "A" will distribute 11,000-volt current in the district about Lomazzo, and "B" and "C" will supply Castellanza. The arrangement is such that one bus-bar system may feed either of the outgoing lines, or that the line "A" to Lomazzo may be fed from the line "C." Through the line "C" 11,000-volt current may be drawn from the steam-power plant at Castellanza of the Societa

Lombarda, which is a reserve for the hydraulic plants at Turbigo and Vizzola. It will be seen that with this auxiliary source of supply, in case of emergency, current may be sent through this station (Lomazzo) and through the station at Piattamala to the hydraulic plant at Brusio.

A fourth line of 20,000 volts leads northward to Como, for which purpose the three-phase, 11,000–20,000-volt transformers were installed.

The feeders from the 50,000–11,000-volt transformers lead to the three-pole oil switches on the mezzanine floor above the aisle, between the two rows of transformers. The feeders to and from the transformers are provided with cutout switches.

The 50,000, 11,000, and 20,000 volt bus-bars are arranged, according to the space available, in horizontal or vertical rows, and the phases separated by concrete shelves or partitions. These bus-bar compartments remain uncovered. The 20,000-volt outgoing feeders are protected like those at the step-up station at Piattamala.

Transformer Station, Castellanza. As previously stated, the Societa Lombarda possesses a steam-power plant at Castellanza, having an equipment of two 2500-HP. engines and two 5000-HP. steam turbines, which work in parallel with the above described hydroelectric plants at Brusio, Turbigo, and Vizzola. A temporary transformer station has been erected in the engine room of this power house, and contains six single-phase, 1250-K.W. transformers arranged in groups of three.

The whole apparatus, owing to the small space available, has been located on three floors. The transformers, which are of the oil, water-cooled type, are designed similarly to those at Piattamala, except for a voltage of 11,000–40,000. Taps are provided, so that some coils may be cut out, to secure a voltage of 35,000. The efficiency of the transformers at full load is 98 per cent, and at half load 97 per cent. The drop in pressure at full load with a power factor of $\cos \phi = 1$ is 1 per cent, while with $\cos \phi = 0.8$ it is 2 per cent. The rise in temperature is 45° C., using five gallons of water in twenty minutes at 15° C. They are capable of standing an overload of 25 per cent, maintaining the temperature of 45° C., and using ten gallons of water, or with a rise of temperature of 60 degrees, using five gallons of water. The transformers were tested at 65,000 volts for a duration of ten minutes.

As the capacity of the steam-power plant is expected to be increased in the near future, an isolated transformer station is now being erected alongside of this power house, which will accommodate eighteen transformers.

The entire installation was put in operation within 2.5 years after the organization of the company, and is giving most satisfactory results, the expectation being that the maximum output will be reached during this year.

THIRTY THOUSAND GENERATOR VOLTAGE TRANSMISSION SYSTEM. DALMATIA, AUSTRO-HUNGARY.[1]

The manufacture of carbide has been carried on extensively, for a number of years, in certain sections of the Austro-Hungarian empire, particularly in Dalmatia and Bosnia. In order to produce carbide on an economical scale, the question of obtaining low-rate electric current was an essential one. This resulted, for a section of Dalmatia, in utilizing the Kerka river to such an extent that this undertaking is one of the foremost hydroelectric developments of Austro-Hungary.

Of the many novel and unique features embodied in the hydraulic and electrical end, the adoption of high-voltage generators, feeding directly a twenty-one mile aerial transmission system, at a potential of 30,000, and its simple, yet highly efficient protecting devices against atmospheric discharges, stand out most prominently. This is another Continental step in the practicability and simplicity of generating current at high voltage, for long transmission systems, without the aid of step-up transformers.

The river Kerka rises at the foot of Dinaria Mountains, forming the boundary between Bosnia and Dalmatia, and flows southwesterly, emptying into the Adriatic Sea, in the bay of Sebenico, below the town Scardona. The Kerka, although comparatively short, has, throughout its length, many scenic falls, varying in height from 25 to 147 feet; the latter, named after the river Kerka and owing to their grandeur, are well known to Dalmatian travelers.

The first hydroelectric plant on this river, and to-day still in operation, was installed at the Kerka Falls in 1894; a 300-HP. Girad turbine, operating under a head of 33 feet, is bevel-geared to a 220-volt, 42-cycle, single-phase generator. The voltage is stepped-up to 3000 volts and transmitted a distance of six miles, to Sebenico, for light and power. With the commercial success of carbide manufacture by electric current in 1898 a second 500-HP. unit was added for experimental purposes in connection with two carbide furnaces.

The present owners of the water rights, Società per la utilizzazione della forze idrauliche della Dalmazia" of Trieste, started up a new plant at Jaruga in 1903, with two 3500-HP. double Francis turbines, operating under a head of 80 feet. They are directly connected to 3000-K.V.A., 42-cycle, two-phase alternators, making 315 R.P.M. The 15,000 generator voltage is directly transmitted, over 9 mm. conductors, to the carbide works, some 6 miles away, not far from the town Sebenico where the voltage is stepped-down to forty-eight by oil-cooled, water-circulated, single-phase transformers. The step-down station adjoins the carbide furnaces, so that the transmission line for 15,000 amperes is very short.

The current from this plant is consumed in eight carbide furnaces, requiring, on the average, 5000 HP per hour throughout the year. With the increased demand for carbide, the factory has been recently extended to accommodate thirty-two furnaces, consuming, on the average, 32,000 HP. per hour throughout the year. For this

[1] Author's article. *Electrical Review*, Jan. 9, 1909. Based on Data Submitted by the Designing and Constructing Engineers.



FIG. 1.—Manojlovac Plant, Dalmatia, Austro-Hungary.

purpose, a new hydroelectric plant, of 24,000-HP. capacity, has been installed at Manojlovac Falls, near Kistanje, some 21 miles upstream, above the Sebenico carbide works. This plant, together with the above-mentioned earlier plants, was designed and installed by Ganz & Co., Budapest, who also supplied all the hydraulic, mechanical and electrical equipments of all these plants.

Near the Manojlovac Falls, the river forms an S, and in the course of 1.2 miles has a drop of 360 feet. The flow varies greatly; in spring, due to snow thaws,

amounting to 1700 cubic feet per second, and in exceptionally dry summer season, to but 350 cubic feet per second.

Manojlovac Plant. Just above the mentioned S, the river forms a natural lake, with an outlet over a natural dam, which is tapped 6.5 feet below the crest, where the inlet to the headrace is provided with three sluice gates. It will be seen that it was unnecessary to build a dam, yet sufficient water is imponded for dry season. The headrace is 5250 feet long, and has a slope of 2 feet in 1000. It has a cross-section area of 117 square feet, cut through the solid rock of the mountain. To reduce skin friction, it is cement-coated up to the water level.

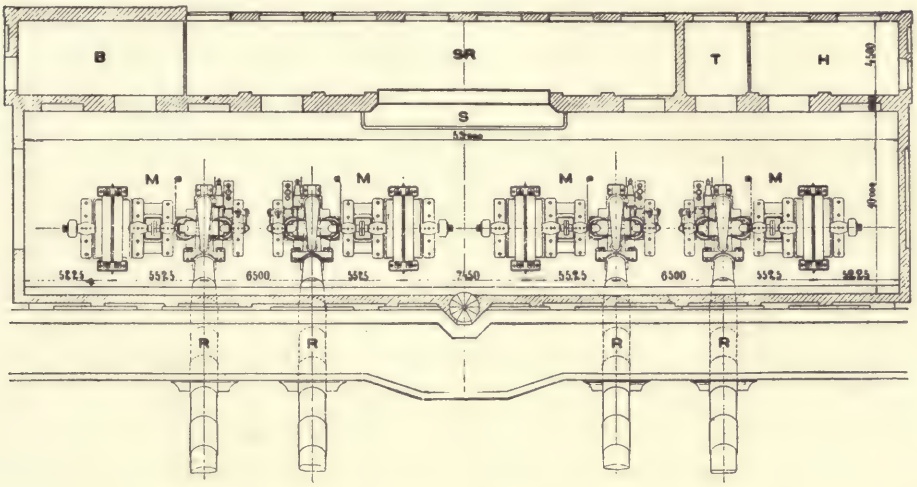


FIG. 2.—Plan of Manojlovac Plant, Dalmatia, Austro-Hungary.

In order to save excavation, two separate collecting basins, joining each other, have been installed. As there are four penstocks, and due to the arrangement of the turbines in the generating room (a right and left hand turbine facing one another), there are two penstock beds.

At the junction of the headrace and collecting basin are fine screens; each inlet to the penstocks is provided with a vertical swinging sector-gate, which is hydraulic-operated, the pressure being supplied by gravity from a reservoir situated on the mountain slope, some 165 feet above the collecting basin. The water for the reservoir is supplied by a small piston pump in the power house, driven by a Pelton wheel, under a head of 328 feet. By this arrangement, the piston pump has to supply water against a head of about 300 feet. Should the supply water fail, provision is made to operate the sector gates manually by worms and gears.

Adjoining the collecting basin is a filtering system of three gravel filters, to supply the hydraulic governors of the turbines. The water is conveyed to same by means of cast iron bell and spigot pipes. The water to the filter system is supplied by a small channel, branching off from the main headrace. Thus the filtering is done by gravity, instead of under pressure, as is the case in many European power plants, where the

connections to the filters are made at the foot of the main penstocks. Of course, with the latter arrangement, a different kind of filtering system is adopted.

The penstocks leave the collecting basin by bellmouthed connections; just outside of the wall are vents, so that, should the sector gates close before the turbines are cut off, the penstocks will not collapse. Each penstock is 558 feet long, 63 inches in diameter, having a shell thickness at the top of one-fourth inch and at the lower end, of nine-sixteenths inch. They were shipped in sections 19.7 feet long, and contrary to the usual practice of bolting same by means of flanges, the sections are riveted together. The penstocks rest on concrete piers; the lower ends are well anchored, while the upper ends are provided with expansion joints.

Generator Room. The turbines are of the Francis spiral type, provided with two draft tubes, and operate under a head of 328 feet, and, with a water consumption of

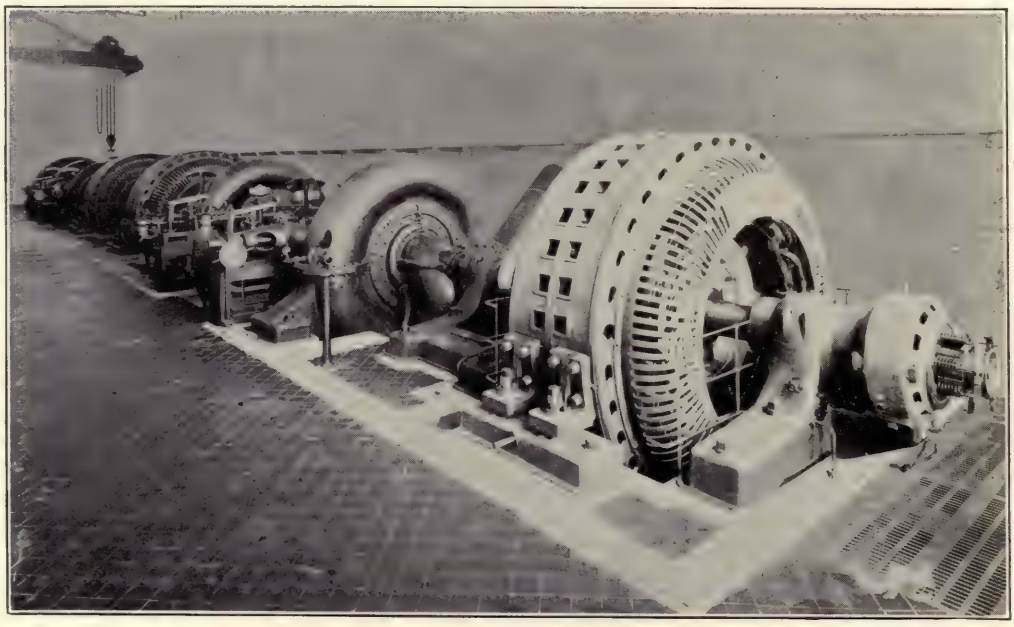


FIG. 3.—Interior of Manojlovac Plant, Dalmatia, showing Four 30,000-volt Generator Units.

212 cubic feet per second, develop, at 420 R.P.M., 66,000 HP. each. Owing to the large units, the double flow was adopted to obviate the side thrust, which in the single flow type is usually overcome by special thrust bearing. The counterbalancing effect is adjusted by regulating the guide vanes.

The regulation of each turbine is accomplished by an hydraulic-actuated governor, which, when the revolutions exceed 10 per cent above the normal, operates a trip lever, which cuts off the supply. As the load is entirely for the manufacture of carbide, a very regular one, the governors come into play practically only when the turbines run away. It requires three seconds to cut off the supply from full to no gate.

The generators of the Ganz & Co. type are rigidly coupled to the shafts of the

A.E.&M.
UNIV. OF CA

turbines; they are of a very unique design. In order to eliminate step-up transformers, the generators, which are the three-phase, 42-cycle type, are designed for 30,000 volts, and at 420 R.P.M., with a power factor 0.8, deliver 5200 K.V.A. each. The efficiencies at full and half load, with power factor 0.8, are 94 and 91 per cent, respectively. When running with full load and a power factor 0.8, at constant speed and excitation, a sudden dropping of the load will cause the voltage to rise 18 per cent. With maximum excitation, the windings will stand a short circuit for two minutes.

The revolving field consists of a cast-steel ring shrunk upon a spider wheel; twelve cast-steel pole cores are fitted into dove-tailed slots and secured by conical bolts.

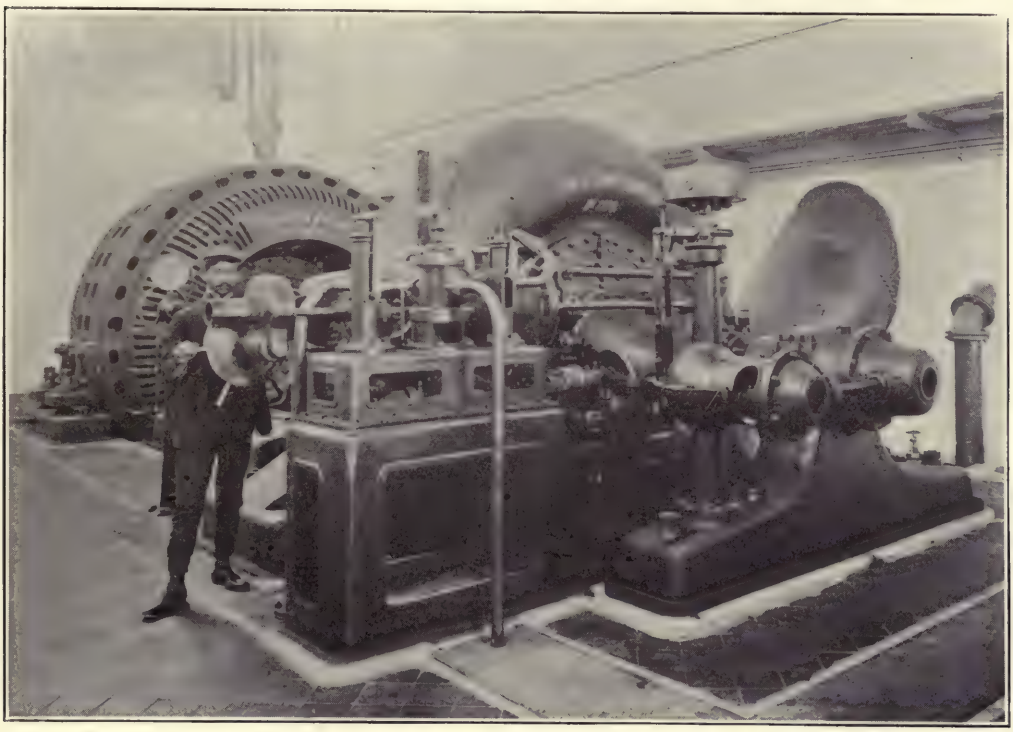


FIG. 4.—6000 HP. Unit, Manojlovac Plant, Dalmatia, Austro-Hungary.

The field windings consist of flat copper strips, wound on edge, and held in place by the pole shoe, which is part of the pole itself. The insulation of the coils consists of paper sheets, and the whole is incased in paper casing, formed to suit the coil. The whole revolving field, with shaft, weighs 26 long tons.

The armature frame consists of halves, which again are split perpendicular to the axis, and when bolted together form a perfect circular ring. It will be observed in the illustration that the feet for the frame are removable; this was provided for the following purpose: the liability of a breakdown in a high-tension generator feeding directly into an overhead transmission line, is greater, owing to atmospheric dis-

charges, than one feeding an underground cable system, or that of a lower-tension generator, feeding transmission lines through step-up transformers.

In the pit, the generator frame rests on two pairs of rollers, by means of which, after the feet have been removed, the whole frame can be revolved, and the lower section be brought on top and removed by the overhead crane, should it be necessary to inspect the coils in the lower half of the armature. By this arrangement it is not necessary to remove the revolving element of the generator.

The coils are machine form-wound in five different shapes. Each is composed of a rectangular copper conductor, wound for twenty-six per slot per phase. The convolutions are insulated by several layers of Micanite, over which are wound several layers of insulating tape. Connections to the coils are made through brass terminals, soldered to the ends of the winding.

Each generator has its own exciter mounted on the overhang of the shaft. The most striking feature of this arrangement is the method by which the exciting current is led to the revolving field. On the extensions of the carbon brush holders are the copper brushes bearing on the collector rings (one of which is insulated), mounted on the shaft, adjoining the commutator. The generator shaft is bored up to the field; through this hole the exciter current is supplied by an insulated cable. The return is through the shaft itself.

The generator bearings are $37\frac{1}{2}$ inches long and $10\frac{5}{8}$ inches in diameter, lined with white metal, and are water-cooled.

Switch Room. Parallel to the generating room in the middle and sunk in the opposite wall, is the switchboard.

There are four generator panels, one collector or totalizing and three outgoing panels. Upon each generator panel are mounted, a rheostat for the exciter field; lever for the generator switch; a volt and ammeter, also voltmeter for excitation; phase lamps, synchronism indicator and double throw switch for parallel operation.

The totalizing panel contains three ammeters and a totalizing recording wattmeter. Further, there are three automatic switch devices, which open the field circuits of all exciters, in case of an excess of generator voltage or current overload, or a diminution of the generator pressure, and by means of the automatic turbine regulator, the water supply to the turbines is cut off.

Each feeder panel has an ammeter and a pilot switch for the overload oil circuit breaker.

Behind the switchboard is the switchroom, the low building above the tailrace; the tower at the end is for the outgoing lines. All the switches and measuring transformers for each machine are placed in concrete cells; wherever possible, the apparatus for each phase is in a separate cell.

The generator switches are of the single-pole, oil type, actuated from the switchboard by means of cable and sheaves. The moving element of each phase of a switch is connected to a common operating shaft. Adjacent to the oil switch cells are those for the series and potential transformers, and so continue for the four generator units. On the roof of the cells are hook switches, also placed in cells. On top of these, is a single set of bus-bars; the different phases are separated by low partitions.

At one end of the bus-bars, after the fourth unit connections, are three double cells containing the general station-protecting devices, consisting, for each phase of the busses, of a condenser submerged in oil; a horn-gap provided with auxiliary gap and a multigap arrester shunted by a resistance placed in oil. From here the busses branch out into two feeders per phase for the two aerial circuits.

The phases of each circuit are provided with overload circuit breakers, potential and series transformers for the ammeters and relays, and hook switches.

From here the lines pass to the upper floor of the tower, and just before leaving the building, each is provided with the following combination of lightning protecting devices; a choke coil with capacity cylinder; a horn-gap with auxiliary gap, by means of which the main gap can be adjusted to a lower breakdown setting than the usual. The horns are shunted by graphite resistance-rods; further, a multigap arrester with shunted resistance; finally, the ground connection is made through continuous water-flow grounders, which lead off light static discharges. The conductors leave the building through porcelain bushings.

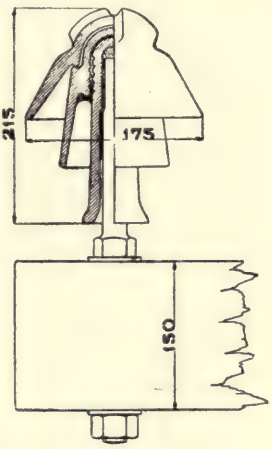


FIG. 5.—Insulator used on 30,000-volt Transmission System, Manojlovac, Dalmatia, Austro-Hungary.

It will be noticed that the protecting equipment is simple, yet very complete; this precaution had to be taken because the generators feed directly an aerial transmission line, which leads through a section of country passing over plateaus, canyons and valleys, very frequently visited by violent thunder storms and other atmospheric electrical discharges.

Transmission System. Both circuits led to the carbide factory near Sebenico, some 21 miles distant, and carried practically the entire length on wooden poles spaced normally 108 feet apart; the lowest conductor is some 19 or 23 feet above the ground.

The conductors are 9 mm. copper wire, carried on three-piece, two-petticoat porcelain insulators, the head diameter being 7 inches, the total height being 8.5 inches. The pin and first petticoat are held together by a glaze of lead and glycerine. The head or second petticoat rests on the first, with an air space between, formed by the ribs on the inside of the head. The insulators were tested at 80,000 volts, and during operation none have broken down.

Where the transmission line crosses small country roads, the poles are placed on either side of the road, where they are also provided with grounded guard arms, so that in case of breakage, the line is grounded; as the spacing is so close, a broken conductor cannot touch the ground. To take up side stresses on turns, the circuits are carried on A-frames. To protect the wooden poles against lightning, each has a pointed castiron cap with a ground wire.

Fig. 6 shows a latticed construction used in crossing the highway and telegraph lines. The bottom and sides of this steel construction are provided with a wire netting.

The transmission lines enter the carbide plant with a similar lightning protection equipment as in leaving the power-house tower, with the exception of the water-flow grounders, owing to the lack of fresh water.

After passing the lightning arresters, connections of the two circuits are made to a common bus-bar system by automatic oil circuit breakers, and series transformers with their recording instruments.

There are installed 12 single-phase oil-cooled water-circulated transformers of 1500 K.V.A. each, stepping-down the line voltage, which is here 26,000, to 48 volts,



FIG. 6.—Transmission Line crossing Highway and Telegraph. In Rear Carbide Plant. Manojlovac System, Dalmatia, Austro-Hungary.

used in the carbide furnaces. The wiring system is so arranged that from the control panel at each furnace, the transformer feeding same can be thrown on to any phase in order to balance the load of the circuit. Again, the division of load between the two furnaces of one transformer is indicated on a differential meter expressing the division of lead in per cent.

There are further two 150-K.V.A. 26,000/330-volt three phase transformers to operate auxiliary apparatus, such as pumps supplying salt water for cooling the transformers; crushers and conveyors for limestone, coal and carbide; repair shops and driving the ventilators of the furnaces, etc.

The Manojlovac plant has been continuously in operation since the earlier part of 1907, and has given entire satisfaction; no trouble has been experienced with the transmission line, or the high tension generators, although the country was frequented by heavy storms and electrical discharges.

INDEX

INDEX.

A.

Action of horn gap lightning arrester, 310.
Adaptability of wooden penstocks, 78.
Air compressors, 281.
Aluminum lightning arrester, 318.
American and European hydroelectric developments, 325.
American Fork plant, penstocks, 85.
turbine, 130.
Ammeter, 191.
Anchors, 71.
Anchor bolts, 106.
insulator, 271.
Appendix, 325.
Application of lightning arresters, 312.
Architectural features, 107.
Area of circles, 60.
Arrangement of substations, 280.

B.

Bar Harbor, Ellsworth, power plant, 27.
Basin, collecting, 56.
Bear traps, 35.
Bearing power of soil, 103.
Beznau roller sluice gate, 33, 34.
Bibliography on mechanical equipment of power plants, 165.
on dams, 38.
on electrical equipment of power plants, 211.
on headraces, 58.
on high tension transmission, 278.
on hydraulic developments, 18.
on line protection, 324.
on substations, 307.
on penstocks, 87.
Bishop Creek plant, penstock, 84.
Bolts, anchor, 106.
Buildings, 101.
bearing power of soil, 103.
character of soil, 103.
concrete mat construction, 106.
excavation, 101.
foundations, 101, 106.
piling, 104.
site for building, 101.
Buildings — *Continued*
test holes, 101.
test of piles, 105.
weight of masonry, 104.
Bus bars, 201.
compartments, 202.
room, Löntsch plant, 203.
room, Lucerne plant, 203.
Ontario, 340.
outdoor, 346.
Butterfly dam, 34.
Brusio plant, Swiss-Italian, 417.
collecting basin, 420.
current supply, 426.
distribution, 433.
gate house, 421.
generators, 423.
headrace, 419.
headrace tunnel, 46.
insulators, 267.
open air cooled transformer, 433.
penstocks, 420.
penstock flange, 68.
penstock flap, 75.
power house, 423.
protecting device, 430.
railway crossing, 431.
secondary water supply, 419.
siphon system, 419.
step-up station, Piattamala, 426.
substation, Castellanza, 434.
substation, Lomazzo, 432.
switch gear, 424.
tower, 247.
transmission lines, 430.
transmission tunnel, 427.
turbines, 423.

C.

Canals, 40.
Cantilever, Niagara Crossing, Ontario, 343.
tower, Obermatt, 246.
Capacity and discharge of penstock, 63.
Castellanza substation, oil switches, 209.
Castelnuovo-Valdarno, switch house, 178.
Channels, water velocity, 41–42.

Chanoine dam, 36.
Chévres plant, France, 54.
Chicago drainage canal, 34.
Choke coils, 315.
Circles, area, 60.
Circuit breakers, 209.
Clamps and ties for insulators, 265, 273.
Concrete, dams, 23.
mat construction, 106.
penstocks, 86.
piling, 105.
Concreted wooden poles, 232.
Conductors, method of tying, 274.
wind pressure, 236.
Conduits, 40.
Converter, field connections, 298.
frequencies, 296.
phase, 298.
starting, 299.
Converters, 296.
compounding, 301.
hunting, 299.
reactances, 301.
Cost of current, 3.
of developments, 3.
of wooden penstocks, 81, 83.
Costs, Uppenborn, 416.
Couplings, 153.
Coffer dam, 26, 29.
Cooling of circulating water for transformers, 293.
Collecting basin, 56.
basin, Brusio, 74, 420.
Colliersville plant, 90–91.
Columns, 123.
Compounding, rotary converters, 301.
Compound Francis turbine, 135.
Conductors, 215.
alternating current conductor, 219.
alternating current, problem, 219.
cables, copper, 224.
cables as, 216.
characteristics, 217.
direct current, 218.
elasticity of, 216.
size, 217.
spacing, 217.
strength of, 215.
corona effect, 226.
direct current problem, 218.
reactance volts, table, 223.
transposition of conductors, 226.
wire gauges, comparison, 220.
wire, solid copper, 221, 225.
stranded copper, 222.
weight and strength of, 223.
Crane, 117.
Crib dam, 26.
Cross arms, 231.
Curtain method, testing turbines, 159.
Cylindrical dams, 36.
gate, 56.

D

Dams, 19.
behavior of resultants, 24.
bibliography, 38.
butterfly, 34
Chanoine, 36.
Charlotte, 352.
coffer, 26, 29.
concrete, 23.
crib, 26.
cylindrical, 36.
earth construction, 32.
earth, Necaxa, 31.
Ellsworth, 28.
gravity, 19.
Heimbach, 394.
masonry, 22.
Necaxa, 372.
needle, 36.
Patapco, 25.
reinforced concrete core, 32.
steel frame, 30.
submerged power plant, 25.
timber, 29.
Dixville, 32.
Deflector in headrace, 49.
Designing staff, 16.
Detail of drum gate, 55.
Development, economy, 15.
first costs, 15.
Developments, investigation, 3.
Direct current switchboards, 187.
Doors, 116.
Draft tubes, 141.
Drawings, charge of extra work, 16.
checking, 16.
and specifications, 16.
Drum gate, 54.
detail, 55.
Duluth substation, 110.

E

Earth dam, Necaxa, 31.
Economy in development, 15.
Economical spans, 250.
Electrolysis prevention, 127.
Electrolytic arrester, 320.
Electrical equipment of power plants, 167.
bibliography, 211.

Elevators, 116.
Ellsworth dam, 28.
El Oro, substation, 381.
Equalizing chambers, 76.
European methods of testing turbine, 157.
Exciters, 173.
wiring diagram, 198.
Expansion slip joints for penstocks, 71–72.
Expansion joints of structural steel, 124.

F.

Field office, 17.
Financial aspect, 362, 403.
Fishways, 37.
Flanges, 66–75.
Flashboards, 36.
Floors, 111, 124.
Floating foundation for transmission tower, 344.
Flow of river, 10.
Fluid arresters, 318.
Flumes, masonry, 42.
timber, 42, 44.
Flywheels, 153.
Flywheel alternator, 169.
with internal stationary armature, 169.
Foundations, 106.
for steel towers, 236, 263.
Four-legged towers, 240, 344.
twin tower, 239.
Forest preservation, 4.
Forebays, 88, 329.
Francis turbines, 131.
Frequencies, 173, 364.
Frequency changers, 303.
meter, 193.
Friction in steel penstocks, 61.
in tunnels, 45.
in wooden penstocks, 80.

G.

Gate house, 74, 331, 420.
valves, 57.
Gates and racks, 47.
Generators, 167.
auxiliaries, 332.
30,000 volt, 175.
leads, 174, 332.
umbrella type, 168.
Brusio, 423.
Charlotte, 355.
Heimbach, 397.
Kykkelsrud, 389.
Manojlovac, 438.
Necaxa, 376.
Generators — *Continued*
Ontario, 332.
Uppenborn, 407.
Geneva plant, 114.
Georgia plant, 89.
Gola lightning protection, 314.
Governors, 143.
Bell, 145.
Escher Wyss, 144.
Lombard, 146.
Glocker-White, 147, 149.
Replogle, 148, 150.
Governmental reports, 13.
Gross horsepower of falling water, 7.
Gradient, hydraulic, 7.
Gravity dams, 19.
Great Falls plant, Southern Power Company, Charlotte, N. C., 348.
auxiliary power, 367.
dam, 352.
financial aspect, 362.
frequency, 364.
generators, 355.
high tension room, 359.
insulator, 364.
lightning protection, 360.
oil switches, 360.
penstocks, 80.
power development, map, 350.
power house, 355.
secondary power, 367.
spillway, 348.
towers, 362.
transformers, 358.
transmission feeder circuit, 361.
lines, 360, 366.
system, map, 349.
turbines, 352.
voltage, 365.
wiring diagram, 356.
Guard wire, 231.
Guys, 232.

H.

Hafslund, deflector and rack, 49.
Hamilton cataract turbine, 140.
Hauser Lake, dam, 30.
Heimbach plant. *See also* Urfttalsperre, 113.
Heimbach plant, wiring diagram, 199.
tower, 246.
Head, loss, 6.
Headrace, arrangement, 39–40.
bibliography, 58.
Brusio, 419.
Heimbach, 395.
Kykkelsrud, 382.
scheme, 39.

Headrace — *Continued*
Sillwerke, 120.
tunnel, Brusio, 46.
Uppenborn, 405.
Heating, 117.
factors of radiating surface, 117.
High head plant, 98.
Holyoke, plant, 89.
tests, 160.
test flume, 161.
Horn gaps, 311.
Horn-gap construction, 313.
setting, 313.
Horsepower, gross, of falling water, 7.
Hunting of converters, 299.
Hydraulics, 5.
fundamental formulæ, 6.
principal formulæ, 6.
Hydraulic gradient, 7.
pipes, riveted, 65.
relief valve, 148.

I.

Induction generator, 167.
regulator, 301.
Innsbruck plant, 174.
Installation of multigap arresters, 317.
Instrument pedestal, 185.
Insulators, 265.
anchor, 271.
Charlotte, 364.
Manojlovac, 441.
Necaxa, 380.
Paderno and Brusio, 267.
strain, 271.
suspended, 268.
Swiss and Italian, 266.
Uppenborn, 410.
Insulator pins, 272–274.
Insulator tie and clamp, 265, 273.
Insulating and rolling support, 271.
Investigation of developments, 3.
Iron sluice gates, 54.
Italian insulators, 266.
steel tower, 247.

J.

Jajce plant, penstock anchor, 70.
wedge shaped expansion joint, 72.

K.

Kaiserwerke, penstock support, 71.
Kern River plant, 97–99.
insulators, 265.
Kern River Plant — *Continued*
penstock, 66.
Kykkelsrud plant, Norway, 102, 382.
exciter units, 388.
generators, 389.
headrace, 382.
power house, 386.
substation, Hafslund, 392.
switchboard room, 390.
transformer room, 390.
transmission line, 391.
turbines, 386.

L.

Lavatories, 119.
Laws of hydraulics, 5.
Leaders, roof, 116.
Length of economical spans, 261.
Lighting, 119.
Lightning arresters, 309.
fluid, 318.
horn type, 311.
location, 323.
multigap, 315.
principle, 309.
Lightning discharges, 309.
Line protection, 309–360.
bibliography, 324.
disconnecting switches, 275.
stresses, 251.
Location of arresters, 323.
of substations, 280.
Loch Leven plant, penstock, run, 73.
Lockport substation, Ontario, 345.
Löntsch plant, bus bar room, 203.
Loss of head in penstock, 6, 61, 62.
Low head plants, 90.
Lucerne, cantilever tower, 246–248.
plant, 112.
bus bar room, 203.
turbine, 144.
wiring diagram, 200.
Lyon plant, France, 56.

M.

Manojlovac plant, Dalmatia, 435.
building, 437.
drainage area, 436.
exciters, 440.
generators, 30,000-volt, 175, 438.
highway crossing, 442.
insulators, 441.
lightning arresters, 442.
line protection, 441.

Manojlovac plant — *Continued*
switch room, 440.
transformers, 442.
transmission poles, 441.
transmission system, 441.
turbines, 438.
Masonry, dams, 22.
flumes, 42.
weight, 104.
Material, building, 111.
McCall Ferry plant, 92–94.
Mechanical equipment of power plants, 129.
bibliography, 165.
Medium head plant, 91, 131.
Meter, Venturi, 11.
water current, 11.
Method of plotting discharge of rivers, 12.
of plotting river bed, 13.
Medium head plants, 91.
Miner's inch, 8.
Molinar plant, Spain, method of cooling circulating water, 293.
Montreal substation frequency changers, 304.
Morgan Fall, Georgia, dam, 22.
Mountain lakes, siphoning, 47.
Motor generators, 302.
Motor generating station, Vienna, 302.
Multigap arresters, 315.
Muskegon 110,000-volt insulator, 270.
tower, 110,000-volt, 249.

N.

Necaxa plant, Mexico, 369.
building, 374.
conductors, 381.
dams, 31, 372.
development, map, 370.
drainage area, 272.
generators, 376.
insulators, 380.
oil switches, 380.
penstocks, 372.
penstock flange, 69.
transmission system, 380.
substation, El Oro, 381.
switching room, 377.
switchboard, 181, 380.
towers, 380.
transformers, 377.
turbines, 376.
wiring diagram, 197.
wiring system, 377.
Needle dam, 36.
New York Central Towers, 245.
Niagara crossing, 342.
Niagara crossing tower, 240.
Niagara, Lockport and Ontario development, 327.
Niagara Falls, 327.
Niagara Falls Power Company plant, 48, 93, 95, 97, 107, 109.

O.

Obermatt, cantilever tower, 246.
plant, 112.
wiring diagram, 200.
switch room, 176–177.
Oil filtering tanks, 154.
piping, 156.
pumps, 156.
required, 154.
rheostat, 312.
switches, 204.
Oiling system, 154.
Ontario plant,
bus bars, 340.
bus bars, outdoor, 346.
cantilever, Niagara, crossing, 343.
circuit breaker, 60,000-volt, 347.
control room, 340.
distributing station, 338.
exciters, 332.
floating foundation for transmission tower, 344.
forebay, 329.
four-legged tower, 344.
gate house, 331.
generator auxiliaries, 332.
generators, 332.
generators, leads, 332.
high tension room, 339.
insulator and pin, 273.
low tension room, 339.
Niagara crossing, 342.
oil switch compartment, 207.
Oneida tower, 243.
open air fuses, 343.
outdoor bus bars, 346.
penstocks, 330.
power house, 332.
screen house, 330.
substation, Lockport, 345.
transformer room, 339.
transmission line, 341.
three-legged towers, 341.
turbines, 332.
wiring diagram, 196.
wiring system, 339.
Outdoor bus bars, Ontario, 346.
disconnecting switch, 276.

Open air fuses, Ontario, 343.
Overload relays, 209.
voltage relay, 211.

P.

Paderno insulator, 268.
Painting of structural steel, 127.
Part I, 1.
Part II, 215.
Part III, 323.
Patapco dam, 25.
plant, 174.
Penstocks, 59.
anchor, 70–71.
air cushion, 76.
American Fork plant, 85.
bibliography, 87.
Brusio, 74, 420.
flanges, 66, 67, 68, 69, 71, 75.
flap, 75.
head loss, 61, 62.
Kern River plant, 66.
Loch Leven, 73.
Necaxa, 372.
Ontario, 330.
protection, 76.
run, 59.
reinforced concrete, 86.
shell, strength, 64.
size, 59.
slip joints, 71, 72.
steel construction, 64.
support, hinged, 71.
vents, 50.
wooden, Bishop Creek, 84.
Piles, tests, 105.
Piling, 104.
Pin insulators, 265.
Piping, oil, 156.
Poles and towers, tests, 238.
Poles, — *see* wooden poles.
Pole and tower construction, 228.
Porcelain base insulator pin, 272.
Portability of steel towers, 237.
Poschiavo siphon system, 47.
Power factor meter, 192.
Power plants, 88.
Bar Harbor plant, Ellsworth, 27.
Brusio, Swiss-Italian plant, 417.
Colliersville plant, 90, 91.
Georgia plant, 89.
Great Falls plant, 348.
Holyoke plant, 89.
Kern River plant, 97, 99.
Kykkelsrud-Hafslund plant, Norway, 382.
Lyon plant, France.
Power plants — *Continued*
Manojlovac plant, Dalmatia, 435.
McCall Ferry plant, 92, 94.
Necaxa plant, Mexico, 369.
Niagara Falls Power Company's plant, 93, 95, 97.
Ontario plant, 309.
Puget Sound plant, 180.
Schaffhausen Low Head plant, 132.
Shawinigan plant, 92.
Sill plant, Tirol, 120.
Snoqualmic plant, 100.
Stuttgart plant, 110.
Toronto plant, 96.
Uppenborn plant, Munich, Germany, 403.
Urfttalsperre plant, Heimbach, Germany, 393.
Winnipeg plant, 89.
Preservation of wooden poles, 231.
Preservation of forest, 4.
Pressure tunnels, 45.
Principle of arresters, 309.
Profile of rivers, 13.
Properties of timber, 53.
Protection of penstocks, 76.
Pumps, oil, 156.

R.

Racks and gates, 47.
Railway crossing, Brusio, 431.
Reactance, converters, 301.
Regulating devices, 143.
Regulation of generators, 170.
Reinforced concrete, dams, 23.
penstocks, 86.
poles, 232.
tower, 234.
Relief valve, 153.
Remote control switchboards, 185.
Reports, governmental, 13.
Reservoirs, 56.
Reverse current relay, 211.
Revolving armature generator, 169.
field alternator, 170.
Rheostats, 193.
River bed, method of plotting, 13.
River, flow, 10.
Rivers, method of plotting discharge, 12.
profile, 13.
velocity of flow, 7.
Riveted hydraulic pipes, 65.
Rochester dead end tower, 242.
Rolling support for long spans, 271.
Roof truss, 122.
Rotary converter connections, 291.

S.

Saddles for penstocks, 72.
Sag at different temperatures, 252.
Sandtraps, 57.
Screens, 49.
Screen, detail, 51.
Screen house, 48, 330.
Scholes, D. R., paper on transmission line towers and economical spans, 253.
Secondary power, Charlotte, 367.
Second-feet, 13.
Section house, Uppenborn, 414.
Section switches, 274.
Seepage in tunnels, 45.
Setting of horn gaps, 313.
Shawinigan plant, 92, 176, 179.
Siegwart concrete poles, 233.
Siphoning lakes, 47.
Siphon system, 46, 419.
Site for buildings, 101.
Size of bus bars, 201.
of units, 280.
Sleet on conductors, 236.
Sluice gate, Stoney, 33–34.
Sluice gates, iron, 54.
wooden, 50–52.
Snoqualmie Falls plant, 100.
Soil, bearing power, 103.
character of, 103.
Spacing of bands on wooden penstocks, 78.
Spans economical, 250.
economical length, 261.
Spier Fall, dam, 22.
Specifications and drawings, 16.
Specification of steel towers, 243.
Spillways, 57.
Spillway, Charlotte, 348.
Spoon wheel turbine, 144.
Stairways, 116.
Standpipes, 76.
Stansstad substation, 115.
Starting of converters, 299.
Steel, frame dam, 30.
insulator pin, 272.
penstocks, 59.
penstock, friction, 61.
pipe towers, 233.
Steel tower, cantilever, 246.
foundations, 236, 263.
Heimbach, 246.
New York Central, 245.
Oneida, 243.
specifications, 243.
Syracuse, 240, 241.
Steel towers and poles, tests, 238.
for suspended insulators, 249, 250.
Steel towers and poles — *Continued*
two-legged, 237.
wind pressure, 235.
Steel transmission towers, 235.
Steghof substation, general arrangement, 285.
Stoney roller sluice gate, 33, 34.
Strain insulators, application, 271.
Strength of Douglas fir, 81.
of penstock shell, 64.
Structural steel, 122.
character of steel, 125.
column bases, 123.
crane column, 124.
expansion joints, 124.
fiber stresses, 125.
floors, 124.
inspection, 127.
painting, 127.
prevention of electrolysis, 127.
typical columns, 123.
typical roof trusses, 122.
workmanship, 126.
Substations, 280.
Substation, arrangements, 280.
bibliography, 307.
Castellanza, 434.
drainage, 281.
Duluth, 110.
Heimbach, 401.
Hirschau, 411, 415.
Hafslund, Kykkelsrud, 390.
location, 280.
Lomazzo, 432.
Piattamala, 426.
Stansstad, 115.
Steghof, 285.
Steghof, motor generator, 303.
switchboard panel, 305.
switch gear, 307.
typical arrangement, 283.
ventilation, 281.
Waterbury, 281.
Superstructure, 107.
Survey, Geological, United States, 13.
Suspended, insulator, 268.
insulator tower, 249–250.
Swiss-Italian steel tower, 247.
Swiss insulators, 266.
penstock flanges, 66, 67.
switching room arrangement, 183, 184, 186.
typical bus bar and wiring system, 195.
wiring practice, 195.
Switchboards, 176.
bus bars chambers, 190.
combined panel, 187.
D. C. board, 187.
desk, type, 185.

Switchboards — *Continued*
exciter or D. C. panel, 186.
high tension A. C. boards, 191.
instrument bench, 186.
low tension A. C. board, 188.
oil switch arrangement, 190.
panel switchboard, 183.
pedestal, or column type, 185.
types of switchboards, 182.
wagon panel, 188, 189, 414.
Switchboard, equipment, 191.
gallery, 116.
Switch gear, Brusio, 424.
for substations, 307.
Necaxa, 380.
Ontario, 356.
panels for substations, 305.
Uppenborn, 407.
Switching room, 176.
Heimbach, 399.
Kykkelsrud, 390.
Manojlovac, 440.
Necaxa, 377.
Puget Sound, 180.
Synchronizing, 192.
Syracuse 45-foot tower, 240–241.
Systems of wiring, diagram, 194.

T.

Tailrace measurement, 159.
Tanks, supply, 156.
Taylor's Fall, insulators, 265.
Telephone, Uppenborn, 416.
Telluride plant, 139.
Test of American woods, 53.
Test holes, 101.
Tests of transmission poles and towers, 238.
of reinforced concrete poles, 233.
Testing turbines, 157.
Three-legged towers, 240–341.
Thrust bearing, 137.
Ties and clamps for insulators, 265, 273.
Timber dam, 29.
flumes, 42, 44.
properties, 53.
Tivoli plant, 121.
Tofwehult-Westerwik rolling support, 271.
Torchio lightning protection, 314.
Toronto plant, 96.
Tower, dead end, Rochester, 242.
reinforced concrete, 234.
Towers, Charlotte, 362.
Necaxa, 380.
steel pipe, 233.
Transmission,
feeder circuit, Charlotte, 361.
Transmission — *Continued*
high tension, bibliography, 279.
lines, Brusio, 430.
Charlotte, 360–366.
Heimbach, 401.
Kykkelsrud, 391.
Ontario, 341.
stresses, 251.
towers and economical spans, 253.
poles, Manojlovac, 441.
— *see* wooden poles.
system, Manojlovac, 441.
Necaxa, 380.
Uppenborn, 410.
towers, Uppenborn, 412.
— *see* steel towers.
transformers, Manojlovac, 442.
tunnel, Brusio, 427.
Transformation of water power, 1.
Transformers, 286.
air cooled, 293.
air required for, 294.
arrangement of air blast, 294.
Charlotte, 358.
characteristics of, 287.
connections of, 290.
core type, 286.
delta vs. Y connection, 290.
efficiency of, 289.
forced oil-cooled transformers, 293.
method of connecting transformers to rotary converters, 291.
oil circulation for cooling, 292.
oil cooled, 292.
regulation of, 288.
shell type, 286.
transformer connections, 290.
characteristics, 287.
efficiency, 289.
Necaxa, 377.
oil circulation, 292.
open air cooled Brusio, 433.
regulation, 288.
room, Kykkelsrud, 390.
room, Ontario, 339.
types of, 286.
Uppenborn, 407.
Traps, bear, 35.
Trenches, 41.
Trenton Water Fall plant, 79.
Tretzo tower, 241.
Tunnels, friction, 45.
pressure, 45.
seepage, 45.
Turbines, 129.
accessories, 152.

A.E.&M. UNIV. OF CAL

Turbines — *Continued*
Brusio, 423.
Charlotte, 352.
curtain carriage testing, 159.
European methods of testing, 157.
graphical registrator, 158.
high head turbines, 138.
Holyoke testing flume, 160.
Heimbach, 397.
Kykkelsrud, 386.
low head, 130.
medium head, 131.
Manojlovac, 438.
Necaxa, 376.
Ontario, 332.
testing, 157.
Uppenborn, 406.
Two-legged tower, Gaucin-Seville, Spain, 237.
tower, Moosburg, 237.
towers, type used in Switzerland and Italy, 237.
Typical arrangement of headrace, 39, 40.
of substations, 283.
Types of oil switches, 204.
steel towers, 259.
switchboards, 182.

U.

Umbrella type generator, 168.
United States Geological Survey, 13.
Uppenborn plant, Germany, 403.
costs, 416.
generators, 407.
generating plant, 406.
headrace, 404.
horn-gaps, 415.
insulators, 410.
lightning arrester station, 411.
lightning protection, 409.
section house, 414.
sluice gates, 405.
substation, Hirschau, 411–415.
switch gear, 407.
telephone, 416.
transmission system, 410.
transmission towers, 412.
transformers, 407.
turbines, 406.
wall outlet, 408.
water flow grounders, 413.
Urfttalsperre, Heimbach plant, Germany, 393.
dam, 394.
financial aspect, 403.
generators, 397.
headrace, 395.
Urfttalsperre, Heimbach plant — *Continued*
power house, 396.
substations, 401.
switching room, 399.
transmission lines, 401.
turbines, 397.

V.

Vacuum relief valve, 77.
Vandoise penstock relief valve, 77.
Velocity of flow in rivers, 7.
Ventilating of power plants, 118.
Ventilation of substations, 281.
Venturi meter, 11.
Vents for penstocks, 50.
Vienna motor generator station, 302.
Voltage, 173.
of converter and frequency, 296.
Voltmeter, 191.

W.

Walls, 111.
Wall outlets, typical, 276–278.
outlet, Uppenborn, 408.
Water, current meter, 11.
flow grounders, Uppenborn, 413.
flow grounders, 321.
power transformation, 1.
velocity in channels, 41–42.
Waterbury substation, 281.
Wattmeter, 191.
Weight of masonry, 104.
Weir dam, 8.
Weirs, construction, 9.
quantity of water passing over, 9.
Windows, 116.
Wind pressure on conductors, 236.
on steel towers, 235.
Winnipeg plant, 89.
Wiring diagrams, 194.
Charlotte, 356.
for exciters, 198.
Heimbach plant, 199.
Necaxa plant, 197.
Obermatt plant, 200.
Ontario plant, 196.
of a single generator and step-up transformer, 201.
Waterbury, substation, 306.
wiring system, Ontario, 339.
Wooden flumes, 42.
piling, 105.
penstocks, 78.
comparative costs, 83.

Wooden penstocks — *Continued*
connection to smaller pipes, 82.
construction, 84.
cost, 81.
durability, 80.
friction, 80.
spacing of bands, 78.
poles, 228.
"A" frame tower, 230.
cross arms, 231.
for three-phase circuit, 229.
kind of wood, 229.
Wooden Poles — *Continued*
life of, 231.
preservation, 231.
strength, 229.
50,000 volts, Taylor's Falls, 228.
pole line construction, 232.
pole guys, 232.
pole, concreted, 232.
sluice gates, 50, 52.
Woods, test of American, 53.
Working strain of penstock bands, 79.
Workmanship on structural steel, 126.

Uniform with "Hydroelectric Developments and Engineering."
8 x 11 inches. 473 Pages. 500 Illustrations. 80 Tables. $5.00 Net.

STEAM-ELECTRIC POWER PLANTS

BY

FRANK KOESTER

CONTENTS: — Problems, Efficiency and Cost of Plants. Location. General Layout. Coal Storage. Condenser Water Supply. Excavation and Foundations. Steel Work. Architectural Features. Boilers. Mechanical Stokers and Grates. Coal. Combustion. Draught. Smoke Flues. Chimneys. Boiler Feed Water. Feed Water Heater. Superheaters. Superheated Steam. High Pressure Piping. Low Pressure Piping. Prime Movers. Reciprocating Engines. Turbines. Condensers. Pumping Machinery. Oiling System. Electrical Equipment. The Design of Small Light and Power Plants. Testing Power Plants. Descriptive Discussion of Five Typical American and European Light and Power Plants. Principal Dimensions and Data of Recently Constructed Light and Power Plants. Tables per K. W. Capacity. Series of Tables.

Recommended by the technical journals, to experts and advanced engineers.
Adapted as text by leading universities.

SOME OPINIONS

"The book represents a lot of diligent work, much research, and investigation; it is fully up to the high standard of the author, who has an international reputation in the engineering profession." — *Electrical Review.*

"This book will undoubtedly take a high place among classical works of the industry; it is evidently the result of an exceptional experience, such as falls to the lot of very few engineers." — *The Electrician.*

"It would be difficult to mention any detail that is not touched upon." — *Power and The Engineer.*

"A very considerable amount of information. — *The Engineering Digest.*

"Probably no other volume contains so much information." — *The Engineering Record.*

"To a great extent a classic on the subject." — *Engineering Times.*

"Considerable value to any student of power engineering." — *Sibley Journal.*

"It is the work of a very experienced engineer; everybody interested in power plants should have this book." — *Zeitschrift des Vereines deutscher Ingenieure.*

"A valuable guide to modern practice." — *Engineering.*

"A comprehensive and useful volume." — *Engineering Review.*

"It is a conscientious guinea's worth." — *Electrical Times.*

D. VAN NOSTRAND COMPANY

PUBLISHERS AND BOOKSELLERS

23 MURRAY AND 27 WARREN STREETS - - NEW YORK

LIST OF WORKS

ON

ELECTRICAL SCIENCE

PUBLISHED AND FOR SALE BY

D. VAN NOSTRAND COMPANY,

23 Murray and 27 Warren Streets, New York.

---

*WRITE FOR COMPLETE 96 PAGE CATALOG, GRATIS

ABBOTT, A. V. The Electrical Transmission of Energy. A Manual for the Design of Electrical Circuits. *Fifth Edition, enlarged and rewritten.* With many Diagrams, Engravings and Folding Plates. 8vo., cloth, 675 pp. . . . . Net, $5.00

ADDYMAN, F. T. Practical X-Ray Work. Illustrated. 8vo., cloth, 200 pp. . . . . Net, $4.00

ALEXANDER, J. H. Elementary Electrical Engineering in Theory and Practice. A class-book for junior and senior students and working electricians. Illustrated. 12mo., cloth, 208 pp. $2.00

ANDERSON, GEO. L. Handbook for the Use of Electricians in the operation and care of Electrical Machinery and Apparatus of the United States Seacoast Defenses. Prepared under the direction of Lieut.-General Commanding the Army. Illustrated. 8vo., cloth, 161 pp. $3.00

ARNOLD, E. Armature Windings of Direct-Current Dynamos. Extension and Application of a general Winding Rule. Translated from the original German by Francis B. DeGress. Illustrated. 8vo., cloth, 124 pp. $2.00

ASHE, SYDNEY W. Electricity Experimentally and Practically Applied. 422 illustrated. 12mo., cloth, 375 pp. . . . . Net, $2.00

ASHE, S. W., and KEILEY, J. D. Electric Railways Theoretically and Practically Treated. Illustrated. 12mo., cloth.

Vol. I. Rolling Stock. *Second Edition.* 285 pp. . . . . Net, $2.50

Vol. II. Substations and Distributing Systems. 296 pp. . . . . Net, $2.50

ATKINSON, A. A. Electric and Magnetic Culculations. For the use of Electrical Engineers and others interested in the Theory and Application of Electricity and Magnetism. *Third Edition, revised.* Illustrated. 8vo., cloth, 310 pp. Net, $1.50

ATKINSON, PHILIP. The Elements of Dynamic Electricity and Magnetism. *Fourth Edition.* Illustrated. 12mo., cloth, 405 pp.....$2.00

Elements of Electric Lighting, including Electric Generation, Measurement, Storage, and Distribution. *Tenth Edition,* fully revised and new matter added. Illustrated. 12mo., cloth, 280 pp.....$1.50

Power Transmitted by Electricity and Applied by the Electric Motor, including Electric Railway Construction. Illustrated. *Fourth Edition,* fully revised and new matter added. 12mo., cloth, 241 pp.....$2.00

AYRTON, HERTHA, The Electric Arc. Illus. 8vo., cloth, 479 pp....Net, $5.00

—— **W. E. Practical Electricity.** A Laboratory and Lecture Course. Illustrated. 12mo., cloth, 643 pp.....$2.00

BAKER, J. T. The Telegraphic Transmission of Photographs. 63 Illustrations. 12mo., cloth, 155 pp.....Net, $1.25

BEDELL, FREDERICK. Direct and Alternating Current Manual. Assisted by C. A. Pierce. *Second Edition, enlarged.* Illustrated. 8vo., cloth, 365 pp. *In Press*

BEDELL, F. & CREHORE, ALBERT C. Alternating Currents. An analytical and graphical treatment for students and engineers. *Fifth Edition.* 112 illustrations. 8vo., cloth, 325 pp.....Net, $2.50

BLAINE, ROBERT, G. The calculus and Its Applications. A practical treatise for beginners especially engineering students. 79 illustrated. 12mo., cloth, 330 pp.....Net, $1.50

BIGGS, C. H. W. First Principles of Electricity and Megnetism. Illustrated. 12mo., cloth, 495 pp.....$2.00

BONNY, G. E. The Electro-Plater's Hand Book. A Manual for Amateurs and Young Students on Electro-Metallurgy. *Fourth Edition, enlarged.* 61 illustrations. 12mo., cloth, 208 pp.....$1.20

BOTTONE, S. R. Magnetos For Automobilists How Made and How Used. A handbook of practical instruction on the manufacture and adaptation of the magneto to the needs of the motorist. *Second Edition, enlarged.* 52 Illustrations. 12mo., cloth, 188 pp.....Net, $1.00

Electric Motors, How Made aud How Used. Illustrated. 12mo., cloth, 168 pp.....75 cents

BOWKER, WM. R. Dynamo, Motor, and Switchboard Circuits for Electrical Engineers: A practical book dealing with subject of direct, alternating, and polyphase circuits. *Second Edition, greatly enlarged.* 130 illustrations. 8vo., cloth, 180 pp.....Net, $2.00

BROADFOOT, S. K. Motors, Secondary Batteries and Accessory Apparatus. Illustrated. 16mo., cloth. (Installation Manuals Series).....*In Press*

CARTER, E. T. Motive Power and Gearing for Electrical Machinery; a treatise on the theory and practice of the mechanical equipment of power stations for electric supply and for electric traction. *Second Edition, revised.* Illustrated. 8vo., cloth, 700 pp. ..... Net, $5.00

CHILD, CHAS. T. The How and Why of Electricity: a book of information for non-technical readers, treating of the properties of Electricity, and how it is generated, handled, controlled, measured, and set to work. Also explaining the operation of Electrical Apparatus. Illustrated. 8vo., cloth, 140 pp. $1 00

CLARK, D. K. Tramways, Their Construction and Working. *Second Edition.* Illustrated. 8vo., cloth, 758 pp. $9.00

COOPER, W. R. Primary Batteries: their Theory, Construction, and Use. 131 Illustrations. 8vo., cloth, 324 pp. ..... Net, $4.00

The Electrician Primers. Being a series of helpful primers on electrical subjects, for the use of students, pupils, artisans, and general readers. *Second Edition.* Illustrated. Three volumes in one. 8vo., cloth, Net, $5 00

Vol. I.—Theory ..... Net, $2.00

Vol. II.—Electric Traction, Lighting and Power. ..... Net, $3.00

Vol. III.—Telegraphy, Telephony, etc. ..... Net, $2.00

CROCKER, F. B. Electric Lighting. A Practical Exposition of the Art for the use of Electricians, Students, and others interested in the Installation or Operation of Electric-Lighting Plants.

Vol. I.—The Generating Plant. *Sixth Edition, entirely revised.* Illustrated. 8vo., cloth, 482 pp. $3.00

Vol. II.—Distributing System and Lamps. *Sixth Edition.* Illustrated. 8vo., cloth, 505 pp. $3.00

—— and ARENDT, M. Electric Motors: Their Action, Control, and Application. 160 Illustrations. 8vo., cloth, 296 pp. ..... Net, 2.50

—— and WHEELER, S. S. The Management of Electrical Machinery. Being a *thoroughly revised and rewritten edition* of the authors' "Practical Management of Dynamos and Motors." *Eighth Edition.* Illustrated. 16mo., cloth, 232 pp. ..... Net, $1.00

CUSHING, H. C., Jr. Standard Wiring for Electric Light and Power. Illustrated. 16mo., leather, 156 pp. $1.00

DAVIES, F. H. Electric Power and Traction. Illustrated. 8vo., cloth, 293 pp (Van Nostrand's Westminster Series.) ..... Net, $2.00

DAWSON, PHILIP. Electric Traction on Railways. 610 Illustrations. 8vo., half leather, 891 pp. ..... Net, $9.00

DEL MAR, W. A. Electric Power Conductors. 69 illustrations. 8vo., cloth, 330 pp. Net, $2.00

DEVEY, R. G. Mill and Factory Wiring. Illustrated. 16mo., cloth. (Installa- Manuals Series) ..... *In Press*

DINGER, Lieut. H. C. Handbook for the Care and Operation of Naval Machinery. *Second Edition.* Illustrated. 16mo., cloth, 302 pp. ..... Net, $2.00

DYNAMIC ELECTRICITY; Its Modern Use and Measurement, chiefly in its application to Electric Lighting and Telegraphy, including: 1. Some Points in Elect.ic Lighting, by Dr. John Hopkinson. 2. On the Treatment of Electricity for Commercial Purposes, by J. N. Schoolbred. 3. Electric-Light Arithmetic, by R. E. Day, M.E. *Fourth Edition.* Illustrated. 16mo., boards, 166 pp. (No. 71 Van Nostrand's Science Series.).....50 cents

EDGCUMBE, K. Industrial Electrical Measuring Instruments. Illustrated. 8vo., cloth, 227 pp.....Net, $2.50

ERSKINE-MURRAY, J. A Handbook of Wireless Telegraphy: Its Theory and Practice. For the use of electrical engineers, students, and operators. *Third Edition, revised and enlarged.* 180 illustrations. 8vo., cloth, 388 pp.....Net, $3.50

—— **Wireless Telephones and How they Work.** Illustrated. 16mo., cloth, 75 pp. $1.00

EWING, J. A. Magnetic Induction in Iron and other Metals. *Third Edition, revised.* Illustrated. 8vo.' cloth, 393 pp.....Net, $4.00

FISHER, H. K. C., and DARBY, W. C. Students' Guide to Submarine Cable Testing. *Third Edition, enlarged.* Illus. 8vo., cloth, 326 pp.....Net, $3.50

FLEMING, J. A. The Alternate-Current Transformer in Theory and Practice.

Vol. I.: The Induction of Electric Currents. *Fifth Issue.* Illustrated. 8vo., cloth, 641 pp.....Net, $5.00

Vol. II.: The Utilization of Induced Currents. *Third Issue.* Illustrated. 8vo., cloth, 587 pp.....Net, $5.00

—— **Propagation of Electric Currents in Telephone and Telegraph Circuits.** Illustrated. 12mo., cloth.....*In Press*

Handbook for the Electrical Laboratory and Testing Room. Two volumes. Illustrated. 8vo., cloth, 1160 pp. Each vol.....Net, $5.00

FOSTER, H. A. With the Collaboration of Eminent Specialists. Electrical Engineers' Pocket Book. A handbook of useful data for Electricians and Electrical Engineers. With innumerable Tables, Diagrams, and Figures. The most complete book of its kind ever published, treating of the latest and best Practise in Electrical Engineering. *Sixth Edition, completely revised and enlarged.* Fully Illustrated. Pocket Size. Leather. Thumb Indexed. 1636 pp.....$5.00

FOWLE, F. F. The Protection of Railroads from Overhead Nransmission Line Crossings. 35 illustrations. 12mo., cloth, 76 rp.....Net, $1.50

FRENDEMACHER, P. W. Electrical Mining Installations. 16mo., cloth. (Installation Manuals Series).....*In Press*

GANT, L W. Elements of Electric Traction for Motormen and Others. Illustrated with Diagrams. 8vo., cloth. 217 pp.....Net, $2.50

GERHARDI, C. H. W. Electicity Meters; their Construction and Management. A practical manual for central station engineers, distribution engineers and students. Illustrated. 8vo., cloth, 337 pp.....Net, $4.00

GEAR, H. B. and WILLIAMS, P. F. Electric Central Station Distribution Systems. Their Design and Construction. 139 illustration. 12mo., cloth. 352 pp.....Net, $3.00

GORE, GEORGE. The Art of Electrolytic Separation of Metals (Theoretical and Practical). Illustrated. 8vo., cloth, 295 pp. .....Net, $3.50

GRAY, J. Electrical Influence Machines: Their Historical Development and Modern Forms. With Instructions for making them. *Second Edition, revised and enlarged.* With 105 Figures and Diagrams. 12mo., cloth, 296 pp.....$2.00

GROTH, L. A. Welding and Cutting Metals by Aid of Gases or Electricity. 124 illustrations. 8vo., cloth, 280 pp.....Net, $3.00

HAMMER, W. J. Radium, and Other Radio Active Substances; Polonium, Actinium, and Thorium. With a consideration of Phosphorescent and Fluorescent Substances, the properties and applications of Selenium, and the treatment of disease by the Ultra-Violet Light. With Engravings and Plates. 8vo., cloth, 72 pp.....$1.00

HARRISON, N. Electric Wiring Diagrams and Switchboards. Illustrated. 12mo., cloth, 272 pp.....$1.50

HASKINS, C. H. The Galvanometer and its Uses. A Manual for Electricians and Students. *Fifth Edition, revised.* Illus. 16mo., morocco, 75 pp...$1.50

HAY, ALFRED. Principles of Alternate-Current Working. *Second Edition.* Illustrated. 12mo., cloth, 390 pp.....$2.00

Alternating Currents; their theory, generation, and transformation. *Second Edition.* 1178 Illustrations. 8vo., cloth, 319 pp.....Net, $2.50

An Introductory Course of Continuous-Current Engineering. Illustrated. 8vo., cloth, 327 pp.....Net, $2.50

HEAVISIDE, O. Electromagnetic Theory. Two Volumes with Many Diagrams. 8vo., cloth, 1006 pp. Each Vol.....Net, $5.00

HEDGES, K. Modern Lightning Conductors. An illustrated Supplement to the Report of the Research Committee of 1905, with notes as to methods of protection and specifications. Illustrated. 8vo., cloth, 119 pp..Net, $3.00

HOBART, H. M. Heavy Electrical Engineering. Illustrated. 8vo.,cloth, 338 pp.....Net, $4.50

—— **Electricity.** A text-book designed in particular for engineering students. 115 illustrations. 43 tables. 8vo., cloth, 266 pp.,.....Net, $2.00

—— **Design of Static Transformers.** 12mo.....*In Press*

HOBBS, W. R. P. The Arithmetic of Electrical Measurements. Withn umerous examples, fully worked. *Twelfth Edition.* 12mo., cloth, 126 pp..50 cents

HOMANS, J. E. A B C of the Telephone. With 269 Illustrations. 12mo., cloth, 352 pp.....$1.00

HOPKINS, N. M. Experimental Electrochemistry, Theoretically and Practically Treated. Profusely illustrated with 130 new drawings, diagrams, and photographs, accompanied by a Bibliography. Illustrated. 8vo , cloth, 298 pp.....Net, $3.00

HOUSTON, EDWIN J. A Dictionary of Electrical Words, Terms, and Phrases. *Fourth Edition, rewritten and greatly enlarged.* 582 Illustrations. 4to., cloth.....Net, $7.00

A Pocket Dictionary of Electrical Words, Terms, and Phrases. 12mo., cloth, 950 pp.....Net, $2.50

HUTCHINSON, R. W., Jr. Long-Distance Electric Power Transmission: Being a Treatise on the Hydro-Electric Generation of Energy; Its Transformation, Transmission, and Distribution. *Second Edition.* Illustrated. 12mo., cloth, 350 pp.....Net, $3.00

—— **and IHLSENG, M. C. Electricity in Mining.** Being a theoretical and practical treatise on the construction, operation, and maintenance of electrical mining machinery. Illustrated. 12mo., cloth.....*In Press*

INCANDESCENT ELECTRIC LIGHTING. A Practical Description of the Edison System, by H. Latimer. To which is added: The Design and Operation of Incandescent Stations, by C. J. Field; A Description of the Edison Electrolyte Meter, by A. E. Kennelly; and a Paper on the Maximum Efficiency of Incandescent Lamps, by T. W. Howell. *Fifth Edition.* Illustrated. 16mo., cloth, 140 pp. (No. 57 Van Nostrand's Science Series.)....50 cents

INDUCTION COILS: How Made and How Used. *Eleventh Edition.* Illustrated. 16mo., cloth, 123 pp. (No. 53 Van Nostrand's Science Series.)...50 cents

JEHL, FRANCIS. The Manufacture of Carbons for Electric Lighting and Other Purposes. Illustrated. 8vo., cloth, 232 pp.....Net, $4.00

JOHNSON, J. H. Arc Lamps and Accessory Apparatus. Illustrated. 16mo., cloth. (Installation Manuals Series).....*In Press*

JONES, HARRY C. The Electrical Nature of Matter and Radioactivity. *Second Edition, completely revised.* 12mo., cloth, 212 pp.....$2.00

KAPP, GISBERT. Electric Transmission of Energy and its Transformation, Subdivision, and Distribution. A Practical Handbook. *Fourth Edition, thoroughly revised.* Illustrated. 12mo., cloth, 445 pp.....$3.50

KAPP, GISBERT. Alternate-Current Machinery. Illustrated. 16mo., cloth, 190 pp. (No. 96 Van Nostrand's Science Series.).....50 cents

Dynamos, Alternators, and Transformers. Illustrated. 8vo., cloth, 507 pp.....$4.00

KELSEY, W. R. Continuous-Current Dynamos and Motors, and their Control; being a series of articles reprinted from the "Practical Engineer," and completed by W. R. Kelsey, B.Sc. With Tables, Figures, and Diagrams. 8vo., cloth, 439 pp.....$2.50

KEMPE, H. R. A Handbook of Electrical Testing. *Seventh Edition, revised and enlarged.* 285 Illustrations. 8vo., cloth, 706 pp....Net, $6.00

KENNEDY, R. Modern Engines and Power Generators. Illustrated. 4to.,

Electrical Installations of Electric Light, Power, and Traction Machinery. Illustrated. 8vo., cloth, 5 vols. The Set, $15.00.....Each, $3.50

KENNELLY, A. E. Theoretical Elements of Electro-Dynamic Machinery. Vol I. Illustrated. 8vo., cloth, 90 pp.....$1.50

KERSHAW, J. B. C. The Electric Furnace in Iron and Steel Production. Illustrated. 8vo., cloth, 74 pp.....Net, $1.50

Electrometallurgy. Illustrated. 8vo., cloth, 303 pp. (Van Nostrand's Westminster Series.).....Net, $2.00

KINZBRUNNER, C. Continuous-Current Armatures; their Winding and Construction. 79 Illustrations. 8vo., cloth, 80 pp.....Net, $1.50

Alternate-Current Windings; their Theory and Construction. 89 Illustrations. 8vo., cloth, 80 pp.....Net, $1.50

KOESTER, F. Hydroelectric Developments and Engineering. A practical and theoretical treatise on the development, design, construction, equipment and operation of hydroelectric transmission plants. 500 illustrations. 4to., cloth, 475 pp.....Net, $5.00

—— **Steam-Electric Power Plants.** A practical treatise on the design of central light and power stations and their economical construction and operation. Fully Illustrated. 4to., cloth, 455 pp.....Net, $5.00

LARNER, E. T. The Principles of Alternating Currents for Students of Electrical Engineering. Illustrated with Diagrams. 12mo., cloth, 144 pp. Net, $1.50

LEMSTROM, S. Electricity in Agriculture and Horticulture. Illustrated. 8vo., cloth.....Net, $1.50

LIVERMORE, V. P., and WILLIAMS, J. How to Become a Competent Motorman: Being a practical treatise on the proper method of operating a street-railway motor-car; also giving details how to overcome certain defects. *Second Edition.* Illustrated. 16mo., cloth, 247 pp.....Net, $1.00

LOCKWOOD, T. D. Electricity, Magnetism, and Electro-Telegraphy. A Practical Guide and Handbook of General Information for Electrical Students, Operators, and Inspectors. *Fourth Edition.* Illustrated. 8vo., cloth, 374 pp.....$2.50

LODGE, OLIVER J. Signalling Across Space Without Wires: Being a description of the work of Hertz and his successors. *Fourth Edition.* Illustrated. 8vo., cloth, 156 pp.....Net, $2.00

LORING, A. E. A Handbook of the Electro-Magnetic Telegraph. *Fourth Edition, revised.* Illustrated. 16mo., cloth, 116 pp. (No. 39 Van Nostrand's Science Series.).....50 cents

LUPTON, A. PARR, G. D. A., and PERKIN, H. Electricity Applied to Mining. *Second Edition.* With Tables, Diagrams, and Folding Plates. 8vo., cloth, 320 pp.....Net, $4.50

MAILLOUX, C. O. Electric Traction Machinery. Illustrated. 8vo., cloth. *In Press*

MANSFIELD, A. N. Electromagnets: Their Design and Construction. *Second Edition.* Illustrated. 16mo., cloth, 155 pp. (Van Nostrand's Science Series No. 64).....50 cents

MASSIE, W. W., and UNDERHILL, C. R. Wireless Telegraphy and Telephony Popularly Explained. Illustrated. 12mo., cloth, 82 pp.....Net, $1.00

MAURICE, W. Electrical Blasting Apparatus and Explosives, with special reference to colliery practice. Illustrated. 8vo., cloth, 167 pp..Net, $3.50

MORECROFT, J. H. and HEHRE, F. W. A Short Course in Testing of Electrical Machinery. Illustrated. 8vo., cloth.....*In Press*

MORGAN, ALFRED P. Wireless Telegraph Construction for Amateurs. 153 illustrations. 12mo., cloth, 220 pp.....Net, $1.50

NIPHER, FRANCIS E. Theory of Magnetic Measurements. With an Appendix on the Method of Least Squares. Illustrated. 12mo., cloth, 94 pp.$1.00

NOLL, AUGUSTUS. How to Wire Buildings. A Manual of the Art of Interior Wiring. *Fourth Edition.* Illustrated. 12mo., cloth, 165 pp.....$1.50

OHM, G. S. The Galvanic Circuit Investigated Mathematically. Berlin, 1827. Translated by William Francis. With Preface and Notes by the Editor, Thos. D. Lockwood. *Second Edition.* Illustrated. 16mo., cloth, 269 pp. (No. 102 Van Nostrand's Science Series.).....50 cents

OLSSON, ANDREW. Motor Control as used in Connection with Turret Turning and Gun Elevating. (The Ward Leonard System.) 13 illustrations. 12mo., paper, 27 pp. (U. S. Navy Electrical Series No. 1.).....Net, .50

OUDIN, MAURICE A. Standard Polyphase Apparatus and Systems. Illustrated with many Photo-reproductions, Diagrams, and Tables. *Fifth Edition, revised.* 8vo., cloth, 369 pp.....Net, $3.00

PALAZ, A. Treatise on Industrial Photometry. Specially applied to Electric Lighting. Translated from the French by G. W. Patterson, Jr., Assistant Professor of Physics in the University of Michigan, and M. R. Patterson, B.A. *Second Edition.* Fully Illustrated. 8vo., cloth, 324 pp.....$4.00

PARR, G. D. A. Electrical Engineering Measuring Instruments for Commercial and Laboratory Purposes. With 370 Diagrams and Engravings. 8vo., cloth, 328 pp.....Net, $3.50

PARSHALL, H. F., and HOBART, H. M. Armature Windings of Electric Machines. *Third Edition.* With 140 full-page Plates, 65 Tables, and 165 pages of descriptive letter-press. 4to., cloth, 300 pp.....$7.50

Electric Railway Engineering. With 437 Figures and Diagrams and many Tables. 4to., cloth, 475 pp.....Net, $10.00

Electric Machine Design. Being a revised and enlarged edition of "Electric Generators." 648 Illustrations. 4to., half morocco, 601 pp..Net, $12.50

PERRINE, F. A. C. Conductors for Electrical Distribution: Their Manufacture and Materials, the Calculation of Circuits, Pole-Line Construction, Underground Working, and other Uses. *Second Edition.* Illustrated. 8vo., cloth, 287 pp.....Net, $3.50

POPE, F. L. Modern Practice of the Electric Telegraph. A Handbook for Electricians and Operators. *Seventeenth Edition.* Illustrated. 8vo., cloth, 234 pp.....$1.50

RAPHAEL, F. C. Localization of Faults in Electric Light Mains. *Second Edition, revised.* Illustrated. 8vo., cloth, 205 pp.....Net, $3.00

RAYMOND, E. B. Alternating-Current Engineering, Practically Treated. *Third Edition, revised.* With many Figures and Diagrams. 8vo., cloth, 244 pp Net, $2.50

RICHARDSON, S. S. Magnetism and Electricity and the Principles of Electrical Measurement. 254 Illustrations. 12mo., cloth, 596 pp.....Net, $2.00

ROBERTS, J. Laboratory Work in Electrical Engineering—Preliminary Grade. A series of laboratory experiments for first and second-year students in electrical engineering. Illustrated with many Diagrams. 8vo., cloth, 218 pp.....Net, $2.00

RUHMER, ERNST. Wireless Telephony in Theory and Practice. Translated from the German by James Erskine-Murray. Illustrated. 8vo., cloth, 224 pp.....Net, $3.50

RUSSELL, A. The Theory of Electric Cables and Networks. 71 Illustrations. 8vo., cloth, 275 pp.....Net, $3.00

SALOMONS, DAVID. Electric-Light Installations. A Practical Handbook. Illustrated. 12mo., cloth.

Vol. I.: **Management of Accumulators.** *Ninth Edition.* 178 pp.....$2.50
Vol. II.: **Apparatus.** *Seventh Edition.* 318 pp.....$2.25
Vol. III.: **Application.** *Seventh Edition.* 234 pp.....$1.50

SEVER, G. F. Electrical Engineering Experiments and Tests on Direct-Current Machinery. *Second Edition, enlarged.* With Diagrams and Figures. 8vo., pamphlet, 75 pp.....Net, $1.00

—— and TOWNSEND, F. Laboratory and Factory Tests in Electrical Engineering. *Second Edition.* Illustrated. 8vo., cloth, 269 pp.....Net, $2.50

SEWALL, C. H. Wireless Telegraphy. With Diagrams and Figures. *Second Edition, corrected.* Illustrated. 8vo., cloth, 229 pp.....Net, $2.00

Lessons in Telegraphy. Illustrated. 12mo., cloth, 104 pp.....Net, $1.00

—— T. Elements of Electrical Engineering. *Third Edition, revised.* Illustrated. 8vo., cloth, 444 pp.....$3.00

The Construction of Dynamos (Alternating and Direct Current). A Textbook for students, engineering contractors, and electricians-in-charge. Illustrated. 8vo., cloth, 316 pp.....$3.00

SHELDON, S., and HAUSMANN, E. Dynamo-Electric Machinery: Its Construction, Design, and Operation.

Vol. I.: Direct-Current Machines. *Eighth Edition, completely rewritten.* Illustrated. 12mo., cloth, 281 pp.....Net, $2.50

Vol. II.: Alternating-Current Machines: *Eighth Edition, rewritten.* 12mo., cloth, 353 pp.....Net, $2.50

—— **Electric Traction and Transmission Engineering.** 127 illustration. 12mo., cloth. 317 pp.....Net, $2.50

SLOANE, T. O'CONOR. Standard Electrical Dictionary. 300 Illustrations. 12mo., cloth, 682 pp.....$3.00

Elementary Electrical Calculations. A Manual of Simple Engineering Mathematics, covering the whole field of Direct Current Calculations, the basis of Alternating Current Mathematics, Networks, and typical cases of Circuits, with Appendices on special subject. 8vo., cloth. Illustrated. 304 pp.....Net, $2.00

SNELL, ALBION T. Electric Motive Power. The Transmission and Distribution of Electric Power by Continuous and Alternating Currents. With a Section on the Applications of Electricity to Mining Work. *Second Edition.* Illustrated. 8vo., cloth, 411 pp.....Net, $4.00

SODDY, F. Radio-Activity; an Elementary Treatise from the Standpoint of the Disintegration Theory. Fully Illustrated. 8vo., cloth, 214 pp..Net, $3.00

SOLOMON, MAURICE. Electric Lamps. Illustrated. 8vo., cloth. (Van Nostrand's Westminster Series.).....Net, $2.00

STEWART, A. Modern Polyphase Machinery. Illustrated. 12mo., cloth, 296 pp.....Net, $2.00

SWINBURNE, JAS., and WORDINGHAM, C. H. The Measurement of Electric Currents. Electrical Measuring Instruments. Meters for Electrical Energy. Edited, with Preface, by T. Commerford Martin. Folding Plate and Numerous Illustrations. 16mo., cloth, 241 pp. (No. 109 Van Nostrand's Science Series.).....50 cents

SWOOPE, C. WALTON. Lessons in Practical Electricity: Principles, Experiments, and Arithmetical Problems. An Elementary Text-book. *Eleventh Edition, enlarged with a chapter on alternating currents.* 404 illustrations. 12mo., cloth, 507 pp.....Net, $2.00

THIESS, J. B. and JOY, G. A. Toll Telephone Practice. 268 illustrations. 8vo. cloth, about 400 pp.....*In Press*

THOM, C., and JONES, W. H. Telegraphic Connections, embracing recent methods in Quadruplex Telegraphy. 20 Colored Plates. 8vo., cloth, 59 pp..$1.50

THOMPSON, S. P., Prof. Dynamo-Electric Machinery. With an Introduction and Notes by Frank L. Pope and H. R. Butler. Fully Illustrated. 16mo., cloth, 214 pp. (No. 66 Van Nostrand's Science Series.).....50 cents

Recent Progress in Dynamo-Electric Machines. Being a Supplement to "Dynamo-Electric Machinery." Illustrated. 16mo., cloth, 113 pp. (No. 75 Van Nostrand's Science Series.).....50 cents

TOWNSEND, FITZHUGH. Alternating Current Engineering. Illustrated. 8vo., paper, 32 pp.....Net, 75 cents

UNDERHILL, C. R. Solenoids, Electromagnets and Electromagnetic Windings. 218 Illustrations. 12mo., cloth, 345 pp.....Net, $2.00

URQUHART, J. W. Dynamo Construction. A Practical Handbook for the use of Engineer Constructors and Electricians in Charge. Illustrated. 12mo., cloth.....$3.00

Electric Ship-Lighting. A Handbook on the Practical Fitting and Running of Ship's Electrical Plant, for the use of Ship Owners and Builders, Marine Electricians, and Sea-going Engineers in Charge. 88 Illustrations. 12mo., cloth, 308 pp.....$3.00

Electric-Light Fitting. A Handbook for Working Electrical Engineers, embodying Practical Notes on Installation Management. *Second Edition,* with numerous Illustrations. 12mo., cloth.....$2.00

Electroplating. *Fifth Edition.* Illustrated. 12mo., cloth, 230 pp.....$2.00

Electrotyping. Illustrated. 12mo., cloth, 228 pp.....$2.00

WADE, E. J. Secondary Batteries: Their Theory, Construction, and Use. *Second Edition, corrected.* 265 Illustrations. 8vo., cloth, 501 pp.....Net, $4.00

WADSWORTH, C. Electric Battery Ignition. 20 Illustrations. 16mo. paper. *In Press*

WALKER, FREDERICK. Practical Dynamo-Building for Amateurs. How to Wind for any Output. *Third Edition.* Illustrated. 16mo., cloth, 104 pp. (No. 98 Van Nostrand's Science Series.).....50 cents

——SYDNEY F. Electricity in Homes and Workshops. A Practical Treatise on Auxiliary Electrical Apparatus. *Fourth Edition.* Illustrated. 12mo., cloth, 358 pp.....$2.00

Electricity in Mining. Illustrated. 8vo., cloth, 385 pp.....$3.50

WALLING, B. T., Lieut.-Com. U.S.N., and MARTIN, JULIUS. Electrical Installations of the United States Navy. With many Diagrams and Engravings. 8vo., cloth, 648 pp.....$6.00

WATT, ALEXANDER. Electroplating and Refining of Metals. *New Edition,* rewritten by Arnold Philip. Illustrated. 8vo., cloth, 704 pp..Net, $4.50

Electro-metallurgy. *Fifteenth Edition.* Illustrated. 12mo., cloth, 225 pp..$1.00

WEBB, H. L. A Practical Guide to the Testing of Insulated Wires and Cables. *Fifth Edition.* Illustrated. 12mo., cloth., 118 pp.....$1.00

WEEKS, R. W. The Design of Alternate-Current Transformer. *New Edition in Press*

WEYMOUTH, F. MARTEN. Drum Armatures and Commutators. (Theory and Practice.) A complete treatise on the theory and construction of drum-winding, and of commutators for closed-coil armatures, together with a full résumé of some of the principal points involved in their design, and an exposition of armature reactions and sparking. Illustrated. 8vo., cloth, 295 pp. ..... Net, $3.00

WILKINSON, H. D. Submarine Cable-Laying, Repairing, and Testing. *New Edition.* Illustrated. 8vo., cloth. ..... *In Press*

YOUNG, J. ELTON. Electrical Testing for Telegraph Engineers. Illustrated. 8vo., cloth, 264 pp. ..... Net, $4.00

ZEIDLER, J. and LUSTGARTEN, J. Electric Arc Lamps. Their principles, construction and working. 160 illustrations. 8vo., cloth, 200 pp. ... Net, $2.00



A 96-page Catalog of Books on Electricity, classified by subjects, will be furnished gratis, postage prepaid, on application.

RETURN TO the circulation desk of any
University of California Library

or to the

NORTHERN REGIONAL LIBRARY FACILITY
Bldg. 400, Richmond Field Station
University of California
Richmond, CA 94804-4698

ALL BOOKS MAY BE RECALLED AFTER 7 DAYS

- 2-month loans may be renewed by calling (510) 642-6753
- 1-year loans may be recharged by bringing books to NRLF
- Renewals and recharges may be made 4 days prior to due date

DUE AS STAMPED BELOW

DEC 1 5 2005

DD20 6M 9-03

749202
TK1081
K7
1911
Engineering Library
UNIVERSITY OF CALIFORNIA LIBRARY